NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

Managing Disaster in the Ionian Sea:
Planning and Optimizing Logistics for Disaster Relief Operations for the Island of Kefalonia

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June 2010

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REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2010			**3. REPORT TYPE AND DATES COVERED** MBA Professional Report
4. TITLE AND SUBTITLE Managing Disaster in the Ionian Sea: Planning and Optimizing Logistics for Disaster Relief Operations for the Island of Kefalonia				**5. FUNDING NUMBERS**
6. AUTHOR(S) Mitsotakis, Adamantios; Kassaras, Georgios				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited				**12b. DISTRIBUTION CODE**
13. ABSTRACT (maximum 200 words) The increasing complexity and magnitude of global emergency relief operations create a critical need for effective and efficient disaster relief logistics. The irregular demand patterns and unusual constraints inherent in large-scale emergencies present unique challenges to logistic systems. Indeed, the logistical needs frequently surpass the capabilities of current emergency response approaches. Our country (Greece) is one of the most seismically active areas in the world. Furthermore, the topography of Greece, with its mountainous terrain and multiple islands, presents challenges in implementing disaster relief operations, especially if one occurs on an island. This project will examine the use of linear programming techniques for optimizing earthquake disaster relief operations in an insular environment. Furthermore, we should note that such problems have direct application to the military environment because assets (personnel, equipment, etc.) of the armed forces are often utilized in disaster relief operations.				
14. SUBJECT TERMS Disaster Relief, Humanitarian Assistance, Military Operations Other than War (MOOTW), Operational Research, Earthquakes, Greece, Ionian Islands, Kefalonia				**15. NUMBER OF PAGES** 233
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified		**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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MANAGING DISASTER IN THE IONIAN SEA: PLANNING AND OPTIMIZING LOGISTICS FOR DISASTER RELIEF OPERATIONS FOR THE ISLAND OF KEFALONIA

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The increasing complexity and magnitude of global emergency relief operations create a critical need for effective and efficient disaster relief logistics. The irregular demand patterns and unusual constraints inherent in large-scale emergencies present unique challenges to logistic systems. Indeed, the logistical needs frequently surpass the capabilities of current emergency response approaches.

Our country (Greece) is one of the most seismically active areas in the world. Furthermore, the topography of Greece, with its mountainous terrain and multiple islands, presents challenges in implementing disaster relief operations, especially if one occurs on an island. This project will examine the use of linear programming techniques for optimizing earthquake disaster relief operations in an insular environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

BPT	Brownian Passage Time
CAV	Cumulative Absolute Velocity
HAF	Hellenic Air Force
HA PUK	Humanitarian Assistance Pack-Up Kit
I	Earthquake Macroseismic Intensity
M	Earthquake Magnitude
M_L	Local Magnitude, or Richter Scale Magnitude
MMI	Modified Mercalli Intensity Scale
M_w	Moment Magnitude
NGO	Non-Governmental Organization
PE	Probability of Exceedance
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
Ro-Ro	Roll On Roll Off Type Ferry Boats that Carry Wheeled Cargo
RT	Return Period
WHO	World Health Organization

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ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to the people listed below who have provided support and advice, and who made this project possible. They were there from its initial concept to its published reality.

From Adamantios Mitsotakis:

I would like to thank my faculty advisors Dr. Aruna Apte and Dr. Geraldo Ferrer for their boundless knowledge, guidance, and mentoring throughout this process.

I would also like to thank my thesis partner, Captain Georgios Kassaras, HAF, for his continuous dedication to the completion of our project.

Finally, I would like to thank my family who followed me in Monterey (which is located 7,000 miles away from our beloved homeland), my wife, Stella, the star of my life, and my son Manos, the meaning of my life, for their support, understanding and encouragement during the time I worked on this project.

From Georgios Kassaras:

I would like to thank both my faculty advisors Dr. Aruna Apte and Dr. Geraldo Ferrer for their encouragement, patience, leadership, and counseling, during the course of this project.

I would also like to thank my thesis partner, Major Adamantios Mitsotakis, HAF, without whose devotion and analytical thinking, the completion of this project would have been impossible.

I have to thank my family in Greece, my father Petros, my mother Katerina, and my brother Gerasimos for their moral support regardless of the great distance that separated us while I was working on this project.

Last, but not least, I would like to thank my beloved wife, Anthy, who followed me in Monterey, separating from her friends and family, for her understanding, support, and the time she spent taking care of me, so I could work on this project undistracted.

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EXECUTIVE SUMMARY

Recent catastrophic earthquakes in Offshore Maule, Chile on February 27, 2010 and Haiti on January 12, 2010, had major consequences for those nations. The international community responded to their appeals for humanitarian aid, pledging funds and dispatching rescue and medical teams, engineers and support personnel; however, damage to vital national infrastructure (such as communication systems, air, land and sea transportation capabilities, hospitals, and electrical networks) hampered those rescue and aid efforts and revealed the complexity of such international ventures. These efforts were further complicated by the confusion over who was in charge, the air traffic congestion, and the prioritization of shipments of relief items. Shortages in supplies, medical care and sanitation led to angry appeals from both aid personnel and survivors. Therefore, the importance is obvious of preparing and issuing, in advance, a timely, efficient, and cost effective plan to transfer the required goods and services to the disaster area.

A lot of research has been done on linear programming models to aid planners by optimizing disaster response logistics. So far, to our knowledge, there has been little or no work done using these methods in a Greek environment for post-earthquake operations. Therefore, this project's intent is to provide a decision tool for Greek humanitarian logistics planners. In addition, tools that are applicable to the Greek environment could be very useful to the Hellenic Armed Forces since they bear a significant portion of the responsibility of conducting such operations.

We chose Kefalonia, a Greek island with a long earthquake history, for application. Two transshipment models for the humanitarian relief items were formulated, solved, and tested in several probable earthquake scenarios that were developed for that purpose. Project integration required the collection and combination of a series of diversified data, such as earthquake historic information, concepts of forecasting earthquake consequences, demographics, air, land and sea transportation capabilities along with the cost and pricing data of these capabilities, which we collected.

The solution of the models provided several useful conclusions. Among them is that the available transportation means are adequate to support the post-earthquake operations in a timely manner. Additionally, the models provided a cost estimation interval, which is very important for budget purposes. The ensuing discussions related to the project are offered to stimulate the interest of senior Greek planners. This is just a first step; much more work is required. For instance, the model may be extended to cover the demand for relief items on neighboring islands that may be hit by an earthquake, or to provide a prioritization schedule of relief item shipments; it may also be used to estimate the pre-establishment requirements of resources that enable efficient relief operations.

I. MANAGING DISASTER

A. CHAPTER OVERVIEW

In this chapter, we review some of the research previously done in modeling disaster relief logistics. The purpose of this review is to provide some insights to the methods, approaches, and practical applications of these techniques, over a variety of real world problems.

B. INTRODUCTION

A disaster is “any occurrence that causes damage, ecological disruption, loss of human life, deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area” (Haghani & Oh, 1996, p. 231). The unpredictability of the time, location, magnitude, and effects of disasters presents unique difficulties in the planning phase for disaster response operations. The framework for analyzing problems related to resource allocation and supply distribution during disaster relief operations has to cope with the inherent uncertainty of these events.

Such problems also have a direct relation to the military environment because in disaster relief operations there is extensive utilization of assets (personnel, vehicles, equipment, supplies, etc.) that fall under the jurisdiction of the armed forces. In Greece, the Ministry of National Defense has a legal responsibility for preparing response plans and making decisions regarding the methods and extent of the necessary contribution (personnel, means, materials, supplies, and their delivery and distribution in the affected areas) during emergency situations and events, according to the National Civil Protection plan, code named “Xenokratis” (Hellenic Government, 2003).

Greece is located in one of the most seismically active areas of the world (Lekidis & Dimitriu, 2002). At the same time, the particular topography of Greece, with its mountainous terrain and numerous islands, presents challenges in managing disaster relief operations. When an earthquake occurs on, or near, an island a response plan will

have to take into consideration the relatively limited access points (ports and airports), posing special problems to the distribution of relief supplies in the post-earthquake phase. These restrictions do not exist when the disaster area can be accessed by land using roads and highways, allowing for an almost constant provision of relief supplies and services, using trucks or other commonly available vehicles.

This project examines the practical applications of mathematical modeling techniques for managing and optimizing earthquake disaster relief operations on an island. The efforts of this research were focused on using these techniques for managing disaster relief logistics, on the Greek island of Kefalonia (also known as Cephalonia, or Kefallinia in the English literature), situated in the Ionian Sea.

C. APPLICATION OF MATHEMATICAL MODELING METHODS IN DISASTER RELIEF LOGISTICS

1. The Development of Linear Programming Models

Linear programming is a set of mathematical methods originating in World War II. George Dantzig, a RAND corporation mathematician, first developed a method known as Simplex to deal with large-scale complex military logistics problems. The Simplex method can be applied to solving very complex problems, as long as they can be formulated in a specific manner. Linear programming models are formulated in a conceptual multidimensional space, where mathematical optimization methods can be used to solve them in a relatively quick and efficient way. A linear programming problem has the objective to minimize or maximize the value of a linear function, by determining the values to a set of decision variables, "subject to a number of linear constraints." If a real-world problem can be mathematically expressed in this form, theoretically it can be solved using the Simplex method (Heidtke, 2007). Although linear programming is a powerful tool, its application in real-world situations poses many challenges, especially when information about future events is uncertain.

2. Modeling with Uncertainty

Successful attempts have been made to model situations involving uncertainty by using mathematical methods, incorporating either a deterministic or a stochastic approach. In a deterministic mathematical model all outcomes are, or can be, “ultimately determined through mathematically defined relationships among states and events, without any room for random [uncertain] variation.” In such models, a given input will always lead to the same unambiguous output. Stochastic models, on the other hand, use random variables, usually described by probability distributions, which means that a given input can produce a variety of outcomes with different probabilities assigned to each of them (www.businessdictionary.com, 2009).

Dantzig was among the first to attempt the formulation of linear programming models dealing with uncertainty (Dantzig, 1955), when he introduced two-stage and multistage models. He suggested that the quantities of the inputs in the first stage are the only ones determined with certainty, while those in the following (later) stages depend on the results of the earlier stages and are random or uncertain. In a two-stage stochastic problem, the two stages are related by the concept of recourse, which is the ability to compensate for initial actions taken under uncertainty, after the occurrence of an uncertain event (Heidtke, 2007). Madansky (1961), Louveaux (1980), and Birge (1985) are some of the authors who reviewed the basic concepts, solution procedures and application areas of linear programming under uncertainty.

Any modeling approach has to rely on assumptions to reflect a real world situation in mathematical terms. These assumptions affect the accuracy and the applicability of a model. All mathematical models are ultimately bound to be an incomplete reflection of reality; the ultimate goal is for them to be accurate enough for the purpose for which they were developed. A model developed for a specific set of circumstances may have to be extensively modified to be useful in a different set, or may not be applicable at all. Sometimes, highly sophisticated and complex models are successfully formulated, but solving them poses severe computational difficulties that might diminish their practical applications. Simplification assumptions that still provide

satisfactory results have to be made, or heuristic processes have to be developed that take shortcuts in the solution process, but at the same time reduce the accuracy of the solution.

As research on using mathematical modeling techniques under uncertainty matured, models tailored for disaster relief logistics were developed, using these methods in various ways.

D. OPTIMIZING DISASTER RELIEF LOGISTICS: LITERATURE REVIEW

1. Previous Research Related to This Project: Overview

Common objectives for this kind of optimization problem are the maximization of the quantity of relief supplies or services delivered through a transportation network and the minimization of response time and transportation costs. In some cases, modeling attempts also focus on optimizing particular phases of disaster relief operations, such as the mission planning of helicopters and their crews, pre-disaster asset prepositioning and post-disaster evacuation, or the planning and scheduling of the means of transportation for the relief supplies. In the research reviewed for the purposes of this project, all the formulated mathematical relationships are linear, allowing for the utilization of linear programming techniques such as the Simplex method.

2. Applicable Time Frame

One interesting observation is the applicable time frame or planning horizon that the reviewed models utilize. In most cases, the post-disaster planning horizon is a relatively short period, 1–3 days into the future (Ozdamar, Ekinzi, & Kucukyazici, 2004; Yi & Ozdamar, 2007; De Angelis, Mecoli, Nikoi, & Storchi, 2007; Balcik, Beamon, & Smilowitz, 2008; Heidtke, 2007; Salmeron & Apte, 2009). There are two important reasons for this; the first is that this is a reasonable way of mitigating uncertainty, since short-term estimations tend to be more accurate than long-term ones. The second reason is that the immediate post-event period is considered the most critical for humanitarian reasons, and it makes sense for a mathematical model intended as a decision support tool

to be focused on this most critical post-disaster period. As time after a disaster event passes, other long-term activities take precedence, such as the restoration of the infrastructure (buildings, roads, etc.).

3. The Mixed Integer Approach

Most of the reviewed research uses mixed integer type linear programming models. The term mixed integer refers to the allowable values for the variables in a mathematical model; some of them are non-negative real numbers and some of them are integer numbers. Non-negative integer variables are used for the modes of transportation (such as number of trucks, ships or aircraft), while non-negative real numbers are used for the quantities of the commodities.

Mixed integer mathematical modeling attempts relative to this project go back to 1996, when Haghani and Oh (1996) dealt with the problem of optimizing the transportation and delivery of various commodities (such as food, clothing, medical supplies, machinery and personnel) using different modes of transportation, through a distribution network from a number of origins to multiple destinations. Their objective was to maximize the survival rate of the affected population and minimize transportation costs. The authors took a multistage approach in the formulation of their model, making it responsive to changes in the transportation network configuration, due to impacts by the emergency and the variation of demand and delivery time requirements. The model is primarily intended as a decision making tool when planning for disaster relief operations.

Barbarosoglou and Arda (2004) developed a model to plan for the transportation of vital first-aid commodities to disaster-affected areas during a post-earthquake emergency response. They made use of earthquake hazard scenarios that portray the impact of earthquakes on an urban area. The model's objectives were the minimization of transportation costs for commodities, and the expected value of the recourse costs, including any penalties for unmet demand requirements.

The researchers divided randomness into two components, reflected in their model by the earthquake scenarios and the impact scenarios. The first component, related

to the epicenter and magnitude, is called the earthquake scenario assessment. The second component of uncertainty is related to the estimation of the consequences of an earthquake, and is known as the impact scenario. In the immediate post-event period, accurate information about the epicenter and magnitude of the earthquake becomes available—this is the first stage. Response and resource mobilization begins at that stage when there is no full and accurate information on the earthquake's impact. The initial response is based solely on the impact scenarios developed in the pre-event period by experts, and as a result its effectiveness also depends on the accuracy of those scenarios.

Ozdamar, Ekinzi, and Kucukyazici (2004) created a model that addresses a dynamic time-dependent transportation problem, which is solved repetitively at specified time intervals. The model's objective was the minimization of the amount of unsatisfied demand in relief location nodes, by optimizing the usage of vehicles and the flow of commodities over the transportation network, for the duration of a planning horizon. This model goes into more detail and also produces the dispatch orders for vehicles waiting at different locations in the disaster area, including route designation, pick-ups and deliveries, for the duration of the planning horizon.

Although the authors agree that knowledge of future demand for commodities is difficult to predict accurately, they assume that a disaster coordination center provides usable information on future supply, and in the model demand for commodities is treated essentially as a deterministic input (it is considered certain). In the model's repetitive solution process, a new plan is generated at specified time intervals by using more recent and accurate information for supply quantities, demand for commodities and vehicle fleet size and composition, as it becomes available.

Yi and Ozdamar (2007) proposed a mixed integer multi-commodity network flow model. Their research focused on the organization of commodity transportation from supply centers to distribution centers located in the disaster area, as well as the transportation of injured persons to temporary or permanent medical emergency units.

This time, the objective was the minimization of the delay in the distribution of items to aid centers in the affected area, and the provision of healthcare services to the injured population.

The model uses a two-stage approach. In the first stage, the optimal vehicle flow is calculated, but vehicles are treated like commodities. This means there is no individual designation or tracking for each of the available vehicles (a truck is a truck, a helicopter is a helicopter, etc.). Future demand in this model is predicted based on current period demand, and treated as a deterministic input. In the second stage, the dispatch orders, pick-up/delivery schedules, and loaded/unloaded quantities for each individual vehicle are calculated.

Balcik, Beamon, and Smilowitz (2008) in particular dealt with the final stage of a humanitarian relief chain. Their model addressed the delivery of relief supplies from local distribution centers to disaster-affected populations, and focused on the last part of the relief supply chain. The model provided support for operational decisions related to the optimization of vehicle delivery schedules and vehicle routes, and maximizing the quantity of commodities delivered to demand locations. The model's objective was the minimization of total transportation costs and penalties for unsatisfied or late-satisfied demand in the relief locations.

In this approach, the demand in the affected area is presumed to be for two generalized types of commodities. Type 1 items are items for which demand is very large and occurs once at the start of the planning horizon (tents, blankets, etc.). In case of unmet demand for type 1 items backorders are allowed, but a penalty cost is charged. Type 2 items are consumables such as food or hygiene kits, and have a periodical demand. Type 2 items cannot be backordered; unsatisfied demand is considered lost and a penalty for lost demand is charged. The authors also creatively modeled vehicle and route compatibility by assigning costs on arcs for each vehicle type. Incompatible vehicles and routes were assigned a very high cost. Using the same approach, damaged or unavailable roads could also be modeled by assigning them very high usage costs, hence making them unattractive for the optimization process. In an attempt to compensate for

the inherent uncertainty in supply and demand over time, the model uses a rolling time horizon. Initial estimates for demand cannot be very accurate; thus, these assessments are updated as more information becomes available.

Heidtke (2007) dealt with the strategic problem of reducing the resource gap between the exhaustion of state and local resources in a disaster area, and the effective resupply effort from federal authorities. The focus of this research was not the development of a new model, but continuing the previous research of Tean (2006), which dealt with the practical applications of an optimization model in disaster relief operations. Heidtke tested Tean's Pre-positioning Optimization Model (POM) as a strategic decision support tool for humanitarian logistics systems. The objective was the development of a methodology for supporting strategic decisions for optimizing the location and usage of public resources, and the efficient organization of a distribution network in a disaster area, given alternative plans of action. This research investigated long-term decisions in the pre-disaster phase (e.g., asset prepositioning infrastructure) and short-term decisions in the post-disaster phase (e.g., the distribution of relief supplies and medical evacuation).

In this approach, five data categories were fed into the model: transportation means, demand for critical commodity by type (such as water, food, medicines, cots, blankets, etc.), affected areas, relief locations, and additional data such as budget and penalty for unmet demand. The commodity requirements were translated into notional dimensions (ft^3) per survivor. Heidtke calculated the expected demand for commodities for the first 72 post-disaster hours. Driving distances and travel times for vehicles in the transportation network were calculated using information from MapQuest.

Salmeron and Apte (2009) developed an optimization model dealing with natural disaster asset prepositioning. This model also handled the decisions, before and immediately after a disaster, for caring for the needs of the affected population and sought to minimize total casualties and suffering, by providing medical evacuation, medical treatment and relocation of the affected population. The model had two objectives: the minimization of total casualties from the critical and stay back population, and the evacuation of transfer population to temporary shelters. Since resources are

shared between the two objectives, the decision-making authority has to set a minimally acceptable level for the first objective, while optimizing the secondary objective.

The decision variables in this model were separated into two stages. The first stage involves the decisions implemented before the disaster event (strategic decisions such as warehouse location). The second stage variables are related to the consequences of a disaster after it has occurred (operational stage decisions, such as the use of various means of transportation).

Some of the research focused on different aspects of disaster relief-related problems, such as the development of a model specifically addressing helicopter mission planning by Barbarosoglu, Ozdamar, and Cevik (2002). This model featured a hierarchical decomposition into two separate sub-problems. The top-level sub-problem modeled tactical decisions (such as helicopter fleet composition, pilot assignment, number of tours per aircraft, etc.), while the base level dealt with operational decisions (such as routing, loading, and refueling). The two objectives were conflicting. The top level's goal was to minimize the cost of assigning helicopters of various types and the pilots to operate them, to air force bases that can accommodate disaster relief operations. The top-level objective pushes for fewer helicopters and more tours per aircraft. The base level's objective was to minimize the "makespan" (Barbarosoglu, Ozdamar, & Cevik, 2002, p. 121) of the solution, by achieving the minimum number of tours assigned to each of the available helicopters; this inevitably calls for more helicopters.

The unique characteristic of this research is that it incorporates an iterative process for the conflicting objectives, in which the top model is solved to generate a fleet composition, which is then used as an input for the base level sub-problem. This process repeats until an acceptable solution pair is achieved. The solution pair is considered acceptable if it satisfies the preference and aspiration functions of the decision-makers, which are also modeled in the iterative process.

4. The Binary Approach

De Angelis, Mecoli, Nikoi, and Storchi (2007) took a different approach than previous researchers when formulating a model for the weekly planning of the World Food Program (WFP) emergency deliveries of food aid in Angola. The goal of this research was the optimization of the delivery schedule so that the total satisfied demand for food aid is maximized. This was achieved by maximizing the number of food delivery trips for the cargo aircraft, within a given timeframe.

In their case, demand is expressed as an integer number of full cargoes that the clients (delivery location) request, and availability as the integer number of full cargoes available for shipment at the depots. All the decision variables in this model were binary (they only assumed values of 0 or 1). This model was unique in an additional way; it was specifically formulated to address the cargo aircraft scheduling for the distribution of food in Angola by the WFP, and for this reason had specially formulated constraints tailored to that setting, such as the use of two types of cargo aircraft of similar capacity but different cruising speeds (3 B-727 and 2 C-130).

5. Methods for Mitigating Uncertainty

Researchers have used different approaches to handle uncertainty in their models. Some of the models reviewed use a two-stage or a multi-stage deterministic approach, where demand and supply for commodities, and the effects of an earthquake, are considered certain, or at least can be estimated accurately enough to be treated as certain (Haghani & Oh, 1996; Ozdamar, Ekinzi, & Kucukyazici, 2004; Yi & Ozdamar, 2007; Balcik, Beamon, & Smilowitz, 2008). Other models use a two-stage stochastic approach with recourse, where demand and supply for commodities in the post-disaster period is described by probability distributions (Barbarosoglou & Arda, 2004; Tean, 2006; Heidtke, 2007; Salmeron & Apte, 2009).

The use of stochastic methods produces more versatile mathematical models and more accurate results over a variety of settings, compared to a deterministic approach. The possible downside is that it could lead to the formulation of complex models, which

might prove difficult to solve, and assumptions have to be made for the probability distribution of uncertain events. On the other hand, the accuracy of the solutions produced by a deterministic model depends on the inherent variability of the input data. High variability reduces a deterministic model's accuracy and a stochastic approach would probably be preferable. A multistage deterministic approach can still be used as the basis for the development of a methodology that produces acceptable results, especially if the planning horizon is short. A multistage approach can also allow for the revision of the optimal solution, if and when more accurate information becomes available. This method requires resolving the model many times, increasing the complexity of the solution methodology, which in turn might reduce its practical applications.

E. APPROACH AND OBJECTIVES FOR THIS PROJECT

After reviewing previous research for the purposes of this project, we decided that the appropriate approach would be the development of a deterministic mixed-integer programming transportation model, with a planning horizon limited to the immediate post-earthquake period (not more than 72 hours), as suggested in the literature (Salmeron, Apte, 2009).

This research is focused on the initial post-earthquake logistics management related to the distribution of relief items using different modes of transportation (air, sea, or ground), from a number of origins to a number of destinations, over a transportation network. The model and research effort is tailored for the Kefalonia Island in the Ionian Sea. The effects and the estimated extent of the damage are modeled through the use of earthquake scenarios based on initial information about the epicenter, location, depth, and magnitude of an earthquake. The objective is the minimization of the total transportation cost within a given time frame. This research is mainly intended to provide a decision support framework and a planning tool for public safety.

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II. INTRODUCTION TO EARTHQUAKES

A. CHAPTER OVERVIEW

Information about an earthquake's intensity is not readily available after its occurrence, since the inflicted damage has to be estimated on site. On the other hand, information about an earthquake's magnitude and epicenter is readily available since magnitude and epicenter can be measured reliably from any seismograph, regardless of its location, or distance from the epicenter. Furthermore, accelerometers located in the affected area can provide information on particular ground motion parameters (ground acceleration and shaking in a very short time after the occurrence). Mathematical functions for estimating macroseismic Intensity based on magnitude, ground motion parameters, and epicentral distance have also been developed. This means that these functions can be used for making preliminary estimations of the impact of an earthquake and as a basis for developing earthquake scenarios for a particular setting. In this chapter, we will present some of the fundamental information needed to understand what earthquakes are, and how earthquakes and their effects are measured.

B. WHAT IS AN EARTHQUAKE

Earthquakes are geodynamic phenomena related to the movement of tectonic plates or, simply, the movement of the Earth's crust (Papazachos & Papazachou, 2003, p. 39). The earth's outer surface is split into many pieces that geologists call tectonic plates. The movement of these plates against each other causes earthquakes along their edges. This shift can be very limited, since one or two meters can cause a big earthquake and just a few millimeters small earthquakes (IRIS Consortium, 1998).

A more precise and formal definition of an earthquake, for the purposes of this project, is "the ground motion caused by the rupture of rocks, as a result of natural causes in the earth's interior" (Hellenic Government, 2003). Earthquakes belong in the same category as other geodynamic events also related to the movement of the Earth's crust, such as the formation of mountains, oceanic trenches, volcanoes, etc. What makes

earthquakes noteworthy among these events and relative to this project is the fact that they can be very disruptive for human activity and can cause massive loss of life and suffering. So far, earth scientists have not been able to develop a methodology for predicting the exact time and location of an earthquake.

C. EPICENTER – HYPOCENTER – FOCAL DEPTH

Some of the basic concepts related to earthquakes are the epicenter and the—less well-known—hypocenter. Both of these essentially refer to the location of an earthquake. In particular, the hypocenter is the exact point underground where a rupture that releases energy and causes an earthquake occurs. The depth of the hypocenter is also described as the focal depth. The epicenter is the corresponding point on the surface directly (vertically) above the hypocenter (United States Geological Survey, 2009). A graphical depiction of epicenter and hypocenter appears in Figure 1.

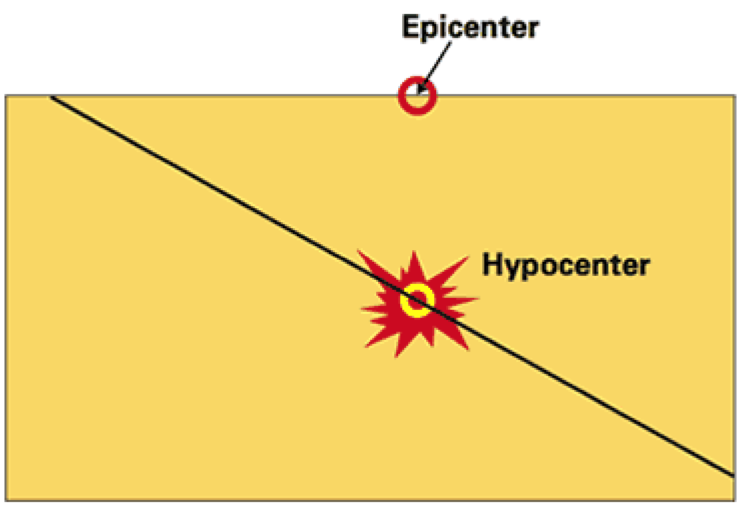

Figure 1. Earthquake epicenter – hypocenter (From: USGS, 2009b)

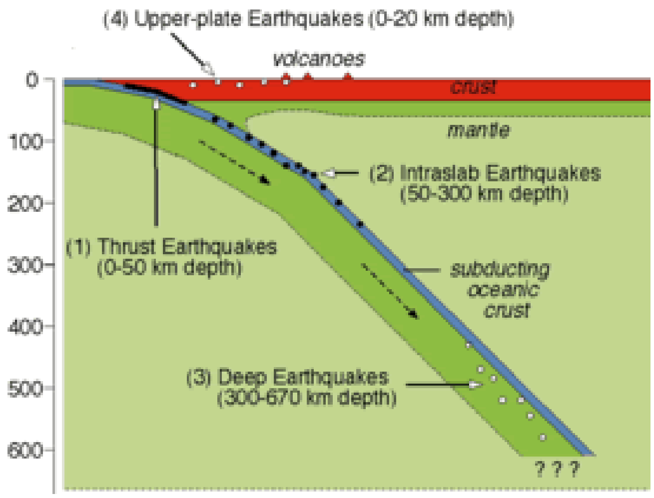

Figure 2. Earthquake focal depth (From: USGS, 2009b)

An earthquake's focal depth varies from the surface to about 700 km down. Scientists usually divide earthquakes into three categories according to their focal depth: shallow (70-300 km), intermediate (70-300 km), and deep (300-700 km) (United States Geological Survey, 1989a). The concepts of epicenter, hypocenter, and focal depth, along with the concepts of magnitude and intensity analyzed later in this chapter, are related to the possible or expected impact an earthquake may have on an area.

D. EARTHQUAKE PROBABILITY DISTRIBUTIONS

Although earthquakes cannot be accurately predicted, attempts have been made to model their probability of occurrence. There are two different approaches for mathematically describing earthquake probabilities: time-independent models and time-dependent models for earthquake occurrence.

1. Time-Independent Models of Earthquake Occurrence

In a time-independent model, the probability of earthquake occurrence in a given period is assumed to follow a Poisson distribution (Petersen, 2007). The time-independent characterization also means that, in this kind of model, probabilities are unrelated to the time of the previous occurrence, and for a given period do not change

over time. The only information needed to compute earthquake probabilities using this approach is the mean recurrence time (also described as the return period, or the recurrence interval), based on historical data. Although this is a simple method, it is considered suitable for guiding decisions regarding public safety, such as building construction safety codes or long-term strategic planning decisions regarding public safety (Petersen, 2007).

2. Time-Dependent Models of Earthquake Occurrence

In contrast, the probability in a time-dependent model of earthquake occurrence depends, among other things, on the time of previous occurrence. More specifically, earthquake probability is assumed to follow a lognormal renewal model, Brownian Passage Time (BPT), or other distribution, in which future probabilities depend on the elapsed time from the last similar event. The BPT distribution is named after the Scottish botanist Robert Brown (1866), who observed the seemingly random movement of particles (plant pollen) floating in a fluid. Mathematical models attempting to describe Brownian motion have many applications, including describing earthquake probabilities of occurrence, something that Brown probably did not envision when he started observing pollen in water under a microscope 140 years ago. A time-dependent model requires additional input besides the mean recurrence time, in particular a measure of the variability of the frequency of earthquakes (variance or standard deviation) and, of course, the last time of occurrence (Petersen, 2007).

3. Assumptions and Limitations for Earthquake Probability Models

In practice, both models are considered scientifically sound approaches for the purpose of modeling earthquake probabilities. We must keep in mind, though, that these models rely on assumptions about the nature of earthquakes and their characteristics, so they cannot be considered a perfect description of earthquake probability, but rather a reasonable approximation. One of the underlying assumptions for both the time-independent and time-dependent models is the “characteristic earthquake model,” a

theory according to which all large earthquakes near a specific fault segment have similar characteristics in magnitude, average displacements, and rupture lengths (Petersen, 2007).

Another assumption for these models is that in the long term all the slips from each individual earthquake add up to the total measured slip rate along the generating fault. This means that the derived probability depends on the magnitude size with which we associate that probability (e.g., greater than or equal to 6.5). Models that include lesser earthquakes will indicate a shorter recurrence time because all the individual smaller slips still have to add up to the total slip rate (Petersen, 2007). Simply put, these models are rigged in such a way that, for a specific location (fault), they suggest smaller earthquakes will happen more often than more significant ones.

E. MEASURING EARTHQUAKES

Over time, scientists have developed different ways and methods for measuring earthquakes. A widespread term when referring to an earthquake's size is its magnitude. Magnitude is an estimation of an earthquakes force and is based on measurements taken from earthquake measuring equipment called seismographs. The magnitude is based on the measurement of the length of seismic waves. This is not a simple task, as there are many different types of earthquake measuring equipment, measuring different characteristics, in various locations, as well as various types of seismic waves associated with each earthquake (Papazachos & Papazachou, 2003, p. 39). Richter (1935) first developed the logarithmic local magnitude scale ($M_{L,}$ L stands for Local), now commonly known as the Richter scale. Since then, other measurement scales have been developed and are in use; some of the most common are the surface magnitude (M_S), body-wave magnitude (M_b), and moment magnitude (M_W) scales (Papazachos & Papazachou, 2003, p. 39; United States Geological Survey, 2009c). All these measurement scales have different mathematical relations to one another, and measurements in one scale can be translated to any other scale for the purposes of keeping uniform records in seismic catalogs. For example:

$$M_W^* = 0.97 M_{LGR} + 0.58, \text{ when } 3.6 \leq \mathrm{M_{LGR}} \leq 6.5 \quad \textbf{(1)}$$

Where

M_W^* is the calculated moment magnitude

M_{LGR} is the local magnitude measured from a Wood-Anderson type seismograph located in Greece (Papazachos & Papazachou, 2003, p. 43).

In this project, we utilize two different measurements for earthquake size: local magnitude (M_L) and moment magnitude (M_W).

1. Richter Logarithmic Scale for Local Magnitude (M_L)

Richter's logarithmic magnitude scale is based on the measurement of the amplitude of seismic waves in Wood-Anderson type seismographs (Papazachos, B., & Papazachou, K., 2003; United States Geological Survey, 2009a). The local magnitude measures the amount of energy released during an earthquake. The Richter scale was originally used for the measurement of earthquakes in California. In the Richter logarithmic scale, local magnitude is expressed in integer positive numbers and decimal fractions. Since the scale is logarithmic, every whole number increase translates into a tenfold increase in the amplitude of the seismic wave, and an increase of approximately 31 times in the energy released by an earthquake. This scale, although it theoretically has no upper or lower limits, is considered applicable for earthquakes up to 6.8 in M_L, after which it does not provide accurate measurements (Ellsworth, 1991). This is one of the reasons why other measurement scales were eventually developed.

2. The Moment Magnitude Scale (M_W)

The moment magnitude scale is, like the Richter scale, a logarithmic scale for the measurement of released energy during an earthquake. The difference is that this scale can be effectively used to uniformly measure all sizes of earthquakes, using different types of seismographs, regardless of their location (United States Geological Survey, 2009c).

Moment magnitude relies on the concept of seismic moment (M_O), which measures the size of an earthquake by its physical characteristics, such as the area of the fault rupture, the average relative displacement on opposite sides of a fault (slip) and the force that was needed to overcome the friction of the rocks. Seismic moment can be calculated by the spectra (graphic representation) of seismic waves. Moment magnitude measurements provide different but comparable results with the Richter scale. The moment magnitude is considered to provide the most reliable representation of an earthquake's size, especially for very large earthquakes (United States Geological Survey, 2009a).

3. Modified Mercalli Intensity Scale (MMI)

Magnitude is determined from seismographs and measures the energy released during an earthquake, but it does not necessarily reflect its impact, because of various other factors, such as the location of the affected area in relation to the epicenter, the vulnerability of the structures, the depth of the rupture, etc. (Lekidis & Dimitriu, 2002). Macroseismic intensity, on the other hand, measures the strength of shaking as a result of an earthquake, in a specific location, and is thus better correlated to its consequences. In fact, intensity is measured by the effects an earthquake has on people, structures, and the environment (United States Geological Survey, 1989b).

The Modified Mercalli Intensity scale (MMI) was developed in 1931 by the seismologists Harry Wood and Frank Neumann and is still widely used in many countries including the United States, and Greece (United States Geological Survey, 1989b). The MMI has twelve designations (in roman numerals) for earthquake macroseismic intensity, ranging from imperceptible (I) to catastrophic destruction (XII). Unlike the magnitude scales that are based on mathematical calculations and the measurable characteristics of an earthquake, the MMI is rather arbitrarily based on the perceived, experienced, or observed effects of an earthquake, and this maybe makes its measurements more meaningful to the non-scientist. Lower numbers on the scale (I-VII) correspond to how an earthquake was felt or experienced by people, while higher numbers (VII-XII) reflect the observed structural damage from an earthquake. This is

why lower numbers can be estimated on the basis of interviews or reports from people in the affected area, but for higher intensity earthquakes structural engineers have to provide input for estimating the extent of the damage.

Because intensity, also called macroseismic intensity, depends on how an earthquake is felt, it also depends on the distance from the epicenter. Higher macroseismic intensity numbers are assigned for the same earthquake in areas near the epicenter and lower numbers as the distance from epicenter increases. The line on a map that goes over all the points of equal intensity for a particular earthquake is called an isoseismal or isoseismic line.

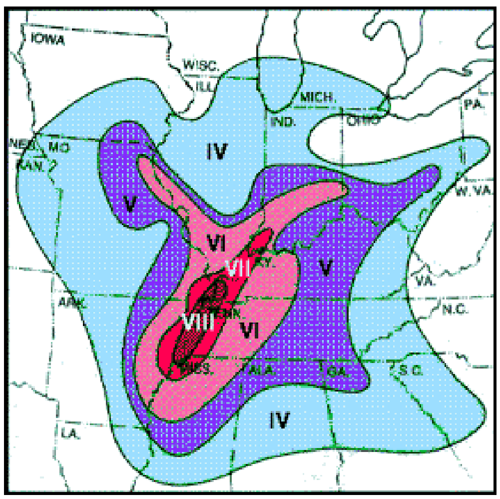

Figure 3. Earthquake intensity – isoseismal lines (From: USGS, 2009f)

As we can see on the map in Figure 3, isoseismal lines are not concentric around the epicenter, suggesting that intensity also depends on many factors besides distance from the epicenter.

In contrast, magnitude measurements are constant regardless of the distance from the epicenter. Table 1 describes the damage associated with each roman number in the MMI (United States Geological Survey):

Table 1. The Modified Mercalli Macroseismic Intensity Scale (From: USGS, 2010)

Intensity		Description
Earthquake intensity as experienced by people	I	Not felt except by a very few under especially favorable conditions
	II	Felt only by a few persons at rest, especially on upper floors of buildings
	III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated
	IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably
	V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop
	VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight
	VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
	VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned
Earthquake intensity estimated by structural damage	IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations
	X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent
	XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly
	XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air

4. Relationship Between Intensity and Magnitude

Although intensity and magnitude measure different characteristics of an earthquake and use incompatible methods (qualitative versus quantitative) to achieve these measurements, empirical relationships between them can be established. These relationships tend to be geographically particular, as they depend on the characteristics of an earthquake's location (e.g., the type of buildings in the area, construction methods, population density, soil hardness, etc.). The United States Geological Survey provides a typical comparison between observed intensity measured in the MMI and magnitude (M_W), for locations near the epicenter, which can be used as a rough guide (United States Geological Survey, 2010a). The comparison is presented in Table 2.

Table 2. Magnitude/Intensity comparison (From: USGS, 2010a)

Recorded Magnitude (Typical maximum)	Observed Intensity
1.0-3.0	I
3.0-3.9	II-III
4.0-4.9	IV-V
5.0-5.9	VI-VII
6.0-6.9	VII-IX
7.0 and higher	VIII and higher

5. Ground Motion Characteristics: Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Cumulative Absolute Velocity (CAV)

The ground motion measures for an earthquake are an alternative way to measure intensity (how an earthquake was felt). Ground motion is measured with accelerometers, and is not as arbitrary or subjective as the MMI, so it can be more useful for estimating the probable effects of an earthquake on buildings and other manmade structures. Building codes set the minimum desired tolerance limits in horizontal force for structures during an earthquake. These limits are directly related to ground acceleration, and the Peak Ground Acceleration (PGA) is the maximum horizontal acceleration experienced by a particle on the ground during an earthquake. Expected PGA values help in the estimation of the possible consequences of an earthquake on a specific location, and are the basis for building code provisions. PGA is considered a sufficient index for seismic hazard for buildings up to seven stories high (United States Geological Survey, 2009d). Other ground motion measures include the horizontal Peak Ground Velocity (PGV), which is a good index for taller buildings, the Cumulative Absolute Velocity (CAV), and the duration of ground motion.

Papazachos and Papazachou (2003, p. 101) provided some relationships for translating ground motion measurements into macroseismic intensity (MMI), specifically for Greece:

Table 3. Macroseismic Intensity and PGA – PGV comparison for Greece (From: Papazachos & Papazachou, 2003)

Intensity (MMI)	PGA (cm/sec^2)	PGV (cm/sec)
VI	110	8
VII	240	16
VIII	510	35
IX	1100	75
X	2340	160

The authors also mentioned that one implication from the values suggested in this table is that, for an earthquake to be damaging in Greece, PGA has to exceed 110 cm/sec^2, and PGV 8 cm/sec (macroseismic intensity of at least VI).

F. SEISMIC RISK AND SEISMIC HAZARD

1. Introduction to Risk and Hazard

Papazachos and Papazachou (2003) defined seismic hazard as a quantity that can be measured by the expected intensity of a strong seismic movement in the location where a structure exists or is going to be built. Intensity in this case can be represented by a measurable ground motion characteristic (PGA, PGV, CAV, etc.) or by the macroseismic intensity (e.g., MMI measurements). Seismic hazard depends on the physical parameters related to a geographical location, such as the type of soil, the expected frequency of earthquake occurrence, the focal depth, etc. Seismic hazard in essence exists beyond human control.

According to the same authors, seismic risk is the expected final social effect from an earthquake in a particular location, such as deaths, building collapses, etc. Seismic risk depends not only on seismic hazard but also on the vulnerability of the infrastructure in a particular location. Seismic engineering deals with methods to reduce vulnerability and, as a consequence, seismic risk. The mathematical relation for seismic risk is:

$$R = H \times V, \qquad \textbf{(2)}$$

Where

R is seismic risk

H is seismic hazard, and

V is the measure of the vulnerability of a particular structure

Seismic engineers use the information provided from seismologists and try to develop methods for minimizing seismic risk. Their efforts usually focus on one of the following two goals (Papazachos & Papazachou, 2003, pp. 97-98):

- The structure should not suffer (ideally) any damage, or should only suffer minor damage, from the most probable earthquake shock expected for the duration of its lifetime (e.g., 50 years).
- The structure is allowed to suffer damage, but it should not collapse from the maximum expected seismic shock in its location.

2. Mathematical Relationships for Estimating Seismic Hazard

When calculating the expected parameters of a significant seismic event for a particular location, such as PGA, PGV, or macroseismic intensity (*I*), a measure *Y* is chosen for this parameter, where *Y* is (Papazachos & Papazachou, 2003, p. 99) given as:

$$Y=loggia,\ or \qquad \mathbf{(3)}$$

$$Y=logPGV\ or$$

$$Y=I\ (macroseismic\ intensity)$$

This parameter is assumed to follow the mathematical relationship:

$$Log\ N_t=\alpha_t-b'Y,\ or \qquad \mathbf{(4)}$$

$$N=N_0exp(-\beta Y)$$

The parameters α_t and b' are location specific and have to be calculated based on historical data (observations) for Y and N_t, something that it is not always easy to accomplish, although previous research provides estimations for these values for every location in Greece.

N_t is the number of earthquakes for which intensity exceeds a specified value of parameter Y in the particular location, for a defined time period of t years (also described as the return period, or recurrence period).

N is the annual number of earthquakes for which intensity exceeds a specified value of parameter Y in the particular location, for a time period of one year, and N_0 and β are calculated as follows:

$$logN_0=\alpha_t-logt \quad \textbf{(5)}$$

$\beta=b'/loge$ (*e* here is the base of the natural logarithm)

The average return period, T_m, for earthquakes whose ground motion characteristics or intensity is equal to or exceeds Y is calculated as follows:

$$T_m = \frac{\exp(\beta Y)}{N_0} \quad \textbf{(6)}$$

Assuming a Poisson distribution for earthquake occurrence, the Probability of Exceedance (PE) for Y in a time period of t years (return period) is:

$$P_t=1-exp(-t/T_m) \quad \textbf{(7)}$$

The probability P_t is usually the measure of seismic hazard for a particular location. Using these calculated probabilities, ground motion hazard maps are created (usually for a given level of probability), similar to the one shown for Greece in Chapter IV (Figure 5). These maps are one of the tools for illustrating the level of seismic hazard for a particular location.

3. Macroseismic Intensity and Distance From the Epicenter

Macroseismic intensity and ground motion parameters (PGA and PGV) depend on the earthquake's magnitude and the particular location's distance from the epicenter. Because of dampening effects, the further away a site is from an earthquake's epicenter, the less it is felt and the less significant are its consequences. Papazachos and Papazachou

(2003, p. 101) provided some mathematical formulas for calculating an earthquake's macroseismic intensity (I in the MMI), PGA and PGV on a site, based on magnitude and epicentral distance:

$I=2.26+1.43M-3.59log(\Delta+6)$, for shallow earthquakes in Greece **(8)**

$I=1.87+1.69M-3.94log(\Delta+30)$, for North Aegean earthquakes specifically

$logPGA=0.33I+0.07$

$LogPGV=0.33I+1.10$

Where

Δ is the distance from the epicenter

M is the magnitude

III. PRESENTATION OF EARTHQUAKES IN GREECE

A. INTRODUCTION

In order to solve the logistics problem of humanitarian relief in case of an earthquake on a Greek island, it is necessary first to understand the earthquake situation in Greece. The work of Papazachos and Papazachou (2003) will be used to define seismic hazard and seismic risk for Greece, and to describe the seismic risk in the region of the island that we study.

B. THE HISTORY OF THE GREEK EARTHQUAKES

Information for the earthquake activity in the geographic area of Greece is available from the 6th century BC onward. Greek and Latin historians (Herodotus, Thucydides, Strabo, Ammines, etc.) described the consequences of great earthquakes that happened from 550 BC to 300 AD. Byzantine writers (e.g., Prokopios, Theofanous, Kedrinos, etc.) provided descriptions during the period 300 AD to 1550 AD. Monks and sightseers continued the practice, in greater detail, during the period 1550 AD to 1845 AD. From the middle of the 19th century, the first efforts at quantitative analysis (apart from earthquake consequences) are noticed. Seismologists of that era tried to record and map the earthquakes' epicenters. Finally, thoroughly quantitative earthquake analyses have been performed over the last forty years. That inquiry is based on:

- The geographical distribution of the rate of release of the seismic energy
- The period of repetition
- The probability of earthquake appearance

The inquiry ended with some basic conclusions regarding the geographical distribution of the chronically independent seismicity in Greece and the neighbor areas. Researchers proved that the seismic actions are scattered and that the seismicity is higher in the Ionian Islands. Results of the inquiry were presented in the epicenter map shown in Figure 4.

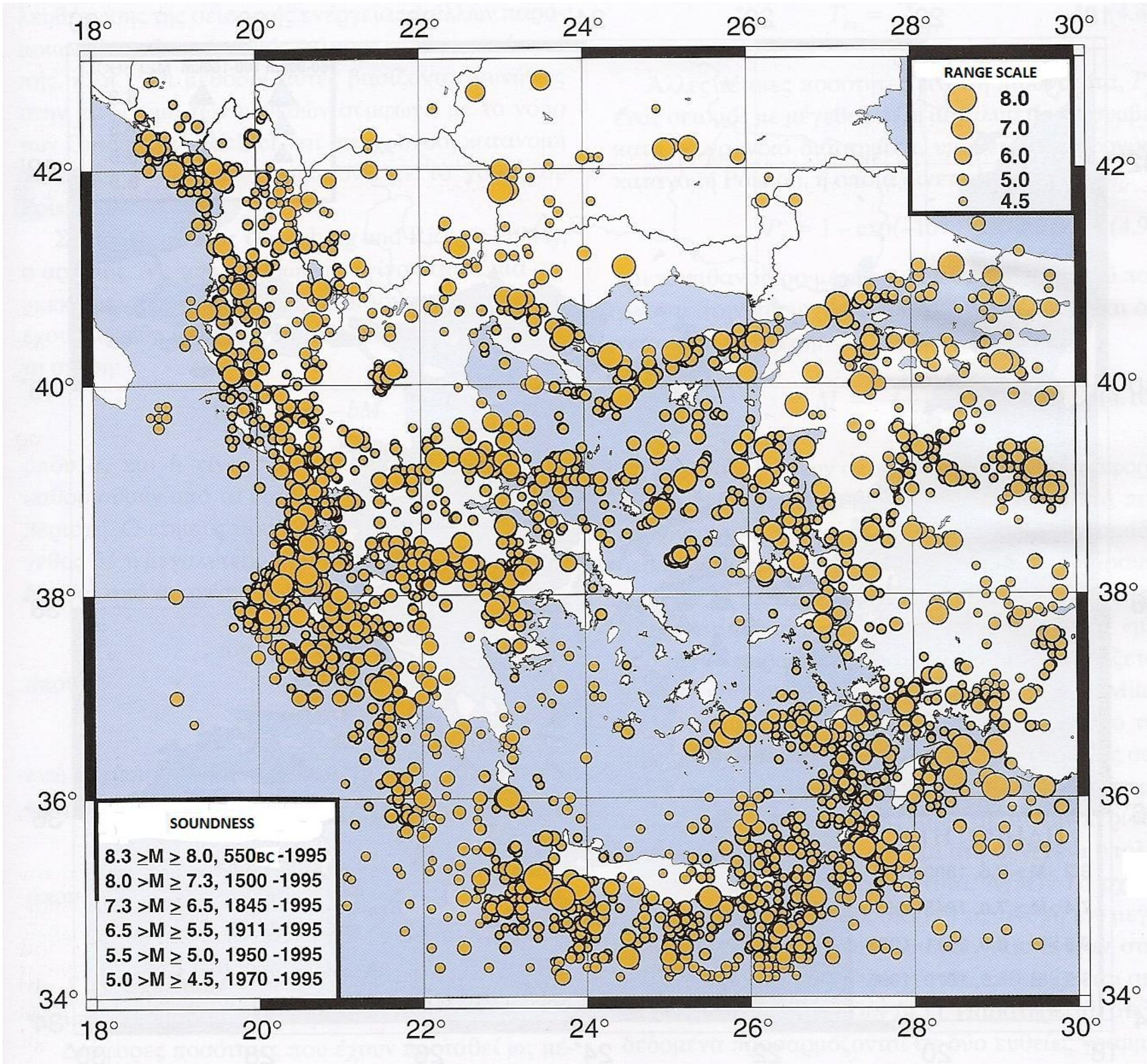

Figure 4. Map of the epicenters of earthquakes in Greece and neighboring countries (From: Papazachos & Papazachou, 2003)

Figure 4 provides a quantitative picture of the earthquake distribution in Greece and neighboring countries. The data that were used are reliable. Figure 4 also shows that seismicity is distributed in two wide areas. The first area includes the arc of the west and south littorals (i.e., western Greece, Ionian Islands, southern Pelloponesos, Crete and Rhodes). The second area includes the northeast-southwest arc (i.e., northern Asia Minor, northern Aegean Sea, central Greece and Ionian Islands). This shows why the Ionian Islands have such high seismic action.

The estimation of the seismicity is reflected either by the average period of recurrence, (return period, presented previously in Chapter II) of specific magnitude earthquakes or the probability of occurrence of an earthquake. The quantitative analysis leads to Table 4, which provides the average return period of earthquakes of seven specific magnitudes. Therefore, in Greece and neighboring countries an earthquake of magnitude equal to or larger than 5 happens every 18 days (=0.05 years), an earthquake of magnitude equal to or larger than 5.5 happens every 2 months (=0.16 years), and an earthquake of magnitude equal to or bigger than 8 happens every 850 years.

C. DEFINITION OF SEISMIC RISK AND SEISMIC HAZARD

The definition of seismic hazard and seismic risk, based on Papazachos and Papazachou (2003), was presented in Chapter II. There, we described seismic hazard (*H*) as location specific and measurable with the expected intensity of a forceful seismic motion at that location, or more precisely with the Probability of Exceedance (PE) of a specified value for a measure of intensity (*I*, PGA, PGV, etc.) in a given time period (return period). The expected final social consequence of such seismic motion in a location (e.g., building damage, human losses, etc.) constitutes the seismic risk (R), which depends on seismic hazard, for that particular location, and the specific characteristics of the structure in question (quality, vibration damp, etc.). The measure of the characteristics of the structure is called vulnerability, V, of the structure.

Table 4. Earthquake return period in Greece and neighboring countries

M (magnitude in Richter's scale)	T (in years)
5.0 ≥	0.05
5.5 ≥	0.16
6.0 ≥	0.5
6.5 ≥	1.8
7.0 ≥	5.8
7.5 ≥	70
8.0 ≥	850

The objective (relative to earthquakes) of sciences such as civil engineering, seismology, etc., is to reduce the seismic risk (i.e., act proactively). Seismology tries to identify, evaluate, and quantify the seismic hazard at a specific location, and then civil engineering tries to respond appropriately to reduce the vulnerability of the structures in that area without excessively burdening the economic cost of those structures. Reduction of the seismic risk is pursued with one of the following goals in mind:

- The structure should not suffer any damage or the structure may suffer minor (easy repairable) damage from the most probable expected earthquake during its lifetime.
- The structure may suffer some damage but it shouldn't collapse from the maximum expected earthquake at the particular location.

Famous Greek seismologists have considered the matter and decided to divide Greece into four hazard zones, according to the estimated seismic hazard level based on the most probable maximum expected PGA values. Those zones are shown in Figure 5. It is assumed that the seismic hazard within those zones is (approximately) constant. That distinction has provided the necessary input for the Greek Anti-Seismic Regulation (building code), which is the standard for building construction in Greece. We will refer to that distinction (in order to be more scientifically accurate we shall use the term distribution) in the next paragraph.

D. GEOGRAPHIC DISTRIBUTION OF SEISMIC HAZARD IN GREECE

Many maps have been suggested by different seismologists to show the geographic distribution of the parameters of major earthquakes. The map in Figure 5 has been suggested by the four Greek seismological institutes (Institute of Technical Seismology and Antiseismic Construction – ITSAK, University of Patras Department of Geology Seismological Laboratory, Aristotle University of Thessaloniki Department of Geophysics, and National Observatory of Athens Institute of Geodynamics).

For each zone, an earthquake's most probable intensity (measured in PGA) can be estimated as the function of a given (desirable) return period. In plain English, it can be estimated as the expected earthquake's intensity for a given period of time:

- Zone I: $\mathrm{LogPGA}=0.266\log T_m+1.424$ **(9)**
- Zone II: $\mathrm{LogPGA}=0.277\log T_m+1.579$
- Zone III: $\mathrm{LogPGA}=0.264\log T_m+1.739$
- Zone IV: $\mathrm{LogPGA}=0.266\log T_m+2.015$

From those functions, it is implied that the weakest earthquakes are expected in Zone I and that the strongest earthquakes are expected in Zone IV. As you can see Kefalonia lies in Zone IV.

The Greek Anti-Seismic Regulation allows maximum PGA limits that are set at about 80% of the limits calculated using these formulas for a return period of T_m=475 years. These limits are PGA 0.12g, PGA 0.16g, PGA 0.24g, PGA 0.36g for Zones I, II, III, and IV, respectively.

Using the map in Figure 5 and equations (8) and (9), one can calculate for every location in Greece the maximum expected macroseismic intensity, PGA and PGV values for any desirable return period. A return period that is close to the actual lifetime of the structure (e.g. T_m=50 years) is used to calculate the most probable maximum value, of I, PGA, or PGV, that the structure has to withstand with minor or no damage. A very big return period (e.g., 1,000 years, or in the building code 475 years) is used to calculate the maximum expected ground motion parameter that will cause damage to a structure, but without causing it to collapse.

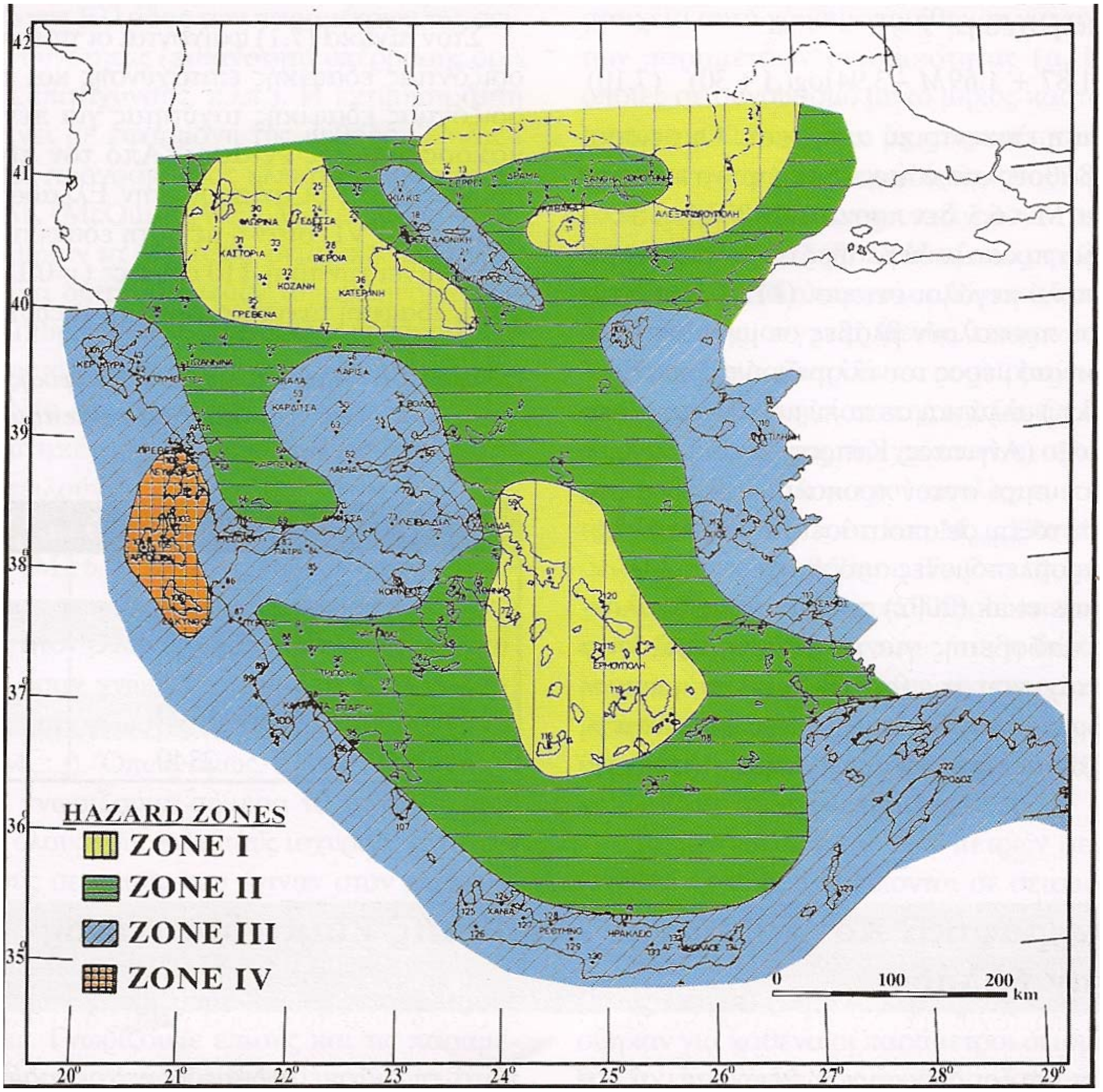

Figure 5. The map of the four zones of seismic hazard that is included in the Greek Anti-Seismic Regulation (From: Papazachos and Papazachou, 2003)

E. ESTIMATION OF SEISMIC RISK IN GREECE

As mentioned above, seismic risk depends on the seismic hazard of the location of a structure and the vulnerability of that structure. Seismic risk is measured by damages to the structures, human losses, and human injuries, and in general by the economic, cultural and social consequences of earthquakes. In this section, we shall try to calculate magnitudes of seismic risk and the consequences of earthquakes in Greece.

1. Structural Damages

Professor Papazachos has created a database that contains information for structural damage caused by the greatest earthquakes of the last 500 years. However, the description of structural damage caused by earthquakes for the last five decades in particular are more accurate and can be used to forecast future earthquakes. Those structural damage assessments are grouped, by the Geodynamic Institute of the Athens Observatory, into four categories:

- Category 1 - structural collapse
- Category 2 - non-repairable damage
- Category 3 - major repairable damage
- Category 4 - minor damage

The distinction between the first two categories is not clear. For that reason, Professor Papazachos combined the first two categories into one group that is named seismic disasters (denoted by letter A in the following diagrams, as the number of structures that either collapsed or have non-repairable damage). A rule of thumb is that the number of non-repairable structures is three times larger than the number of collapses. Correspondingly, the distinction between the other two categories is not clear, either. Therefore, Professor Papazachos combined those two categories into a group that is named seismic damages (denoted by letter B in the following diagrams, as the number of the structures that suffered either major or minor repairable damage). A rule of thumb is that the number of structures with minor damage is twice as large as the number of structures with major damage.

Information about the damage caused by earthquakes circa 1950–1986 is shown in Table 5, and includes the following:

- The maximum intensity of earthquakes that caused disasters and damage in Greece during that period
- The average number of structures that were either destroyed (collapses and non-repairable damage noted as $\bar{A}$) or damaged (major or minor repairable damage noted as $\bar{B}$) from an earthquake of the given intensity
- The average number of earthquakes of specific intensity (noted as n)

- The annually expected number of structures that were either destroyed (collapses and non-repairable damage, noted as E_A and equal to the product of $\bar{A}$ and the average number of earthquakes) or damaged (major or minor repairable damage, noted as E_B and equal to the product of $\bar{B}$ and the average number of earthquakes).

Table 5. Structural damage caused by Earthquakes in Greece, 1950–1986

I_o	$\bar{A}$	$\bar{B}$	n	E_A	E_B
VIII	200	500	0.78	156	390
VIII+	1300	4800	0.36	468	1728
IX	4200	9000	0.17	714	1530
IX+	6000	9500	0.08	480	760
X	8500	12000	0.04	340	480
X+	10000	9000	0.03	300	270

The following conclusions are drawn from Table 5:

- The annually expected number of structures destroyed is 2500
- The annually expected number of structures damaged is 5200
- Earthquakes that have macroseismic intensity VIII+ and IX (those earthquakes having magnitudes from 6 to 7 on the Richter scale) cause the most damage.

Papazachos concluded that the expected cost of rehabilitation of the destroyed and damaged structures is U.S. $600 million.

2. Human Injuries and Losses

Human injuries and losses have also been examined, and the derived data entered by Papazachos into a database. Data from that database were analyzed and the following conclusions made:

- The most deadly earthquake of the last 300 years happened on Chios in 1881—3,550 people lost their lives and around 7,000 people were injured.
- The most deadly earthquake of the last 50 years happened on Kefalonia on 12 August 1953. In that earthquake, 476 people lost their lives and 2,412 people were injured.

- The maximum number of dead and injured people was recorded during the 19th century.

However, since the data before 1800 are incomplete, inaccurate and unreliable, it is not certain that the 19th century was the most deadly from an earthquake perspective. Additionally, the human losses and injuries in the 20th century were significantly less than those in the 19th century, because the structures improved after World War II and better material and techniques were used.

Therefore, in order to have a more accurate perception of human losses and injuries due to earthquakes in Greece, Papazachos used data from the period 1950-1985. It is believed that data from that era are more reliable because the material used and the techniques applied to those structures are similar (or the same) to the modern (and near future) structures. So, the conclusions from the processing of such data may be used in the study of near future earthquakes.

Those data have been summarized in Table 6, which shows the following:

- The maximum intensity of earthquakes that caused disasters and damage in Greece during that period (1950-1985).
- The average number of human losses (noted as $\bar{K}$) and the average number of injured people (noted as $\bar{D}$) for earthquakes of specific intensities.
- The average number of earthquakes of specific intensities (noted as n).
- The annually expected number of human losses (noted as E_D and equal to the product of $\bar{D}$ and the average number of earthquakes) or injuries (noted as E_K and equal to the product of $\bar{K}$ and the average number of earthquakes).

Table 6. Human losses and injuries that were caused by Earthquakes in Greece, 1950–1985

I_o	$\bar{D}$	$\bar{K}$	n	E_A	E_B
VIII	0.85	4.68	0.78	0.66	3.65
VIII+	2.69	14.79	0.36	0.97	5.32
IX	8.51	46.77	0.17	1.47	7.95
IX+	26.91	147.91	0.08	2.15	11.83
X	85.11	467.74	0.04	3.40	18.71
X+	269.15	1479.11	0.03	8.07	44.37

From Table 6, the following conclusions are implied:

- Human injuries are five times greater than human losses
- The more intense an earthquake is (X, X+), the more human losses and injuries there will be
- On average, we may expect 20 human losses and 100 human injuries per year due to earthquakes
- During the period 1950–1986, 800 people died and 4,500 were injured due to earthquakes

3. Other Earthquake Consequences

Earthquakes may have other social consequences apart from human loss and structural damage. The consequences may be economic, humanitarian, cultural, or psychological.

The economic consequences are distinguished as direct and indirect. Earthquakes' direct economic consequences are caused by reasons other than structural damage. Some examples are tsunamis, falling rocks and buildings, and especially fire. Fire is caused by electrical shorts, destruction of fireplaces and furnaces, or damaged natural gas pipes. The fire that followed the earthquake of 1953 completed the destruction begun by the initial event.

Earthquakes' indirect economic consequences are caused by the interruption of economic activities by the event. People don't work for several days after an earthquake and the production is reduced.

Humanitarian consequences are related to human losses that follow an earthquake for reasons other than structural collapses. These can include deaths due to epidemics or shortages in health care.

Cultural consequences are related to the destruction of ancient monuments. Greece has experienced the destruction of masterpiece monuments such as the Colossus of Rhodes, the gold statue of Zeus at Olympia, etc.

Psychological consequences cause terror, upset and over-excitability among the residents of the location where an earthquake occur. In several cases, earthquakes have been exaggerated and this may lead to panic and to an increase in human losses and injuries. This happens because of insufficient knowledge about earthquakes and because, after an earthquake, homes are usually converted (emotionally) from human protectors (against cold, heat, thefts, etc.) to human enemies.

Finally, earthquakes may cause emigrations. The most recent example is Haiti, where civilians fled to the Dominican Republic. This may be seen as a humanitarian consequence.

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IV. KEFALONIA

A. INTRODUCTION

The island of Kefalonia is named after the mythological figure Cephalus (=Κέφαλος). However, some believe its name literally means "island with a head," referring to the island's shape; the name "Ciphalis" (=Κεφαλή) is derived from the Greek word "head" (Kefaloniainfo.com, n.d.).

Perhaps the best-known appearance of Kefalonia is in the 2001 movie of Studio Universal Pictures, "*Captain's Corelli Mandolin.*" The movie was based on the novel "Corelli's Mandolin" by the English author Louis de Bernieres, which is believed to be inspired by the picturesque village of Farsa, just outside of Argostoli (Captain Corelli's Mandolin, n.d.).

The movie's poster (Figure 6) presents three characteristics of Kefalonia that we must keep in mind for our project. First, it is a great vacation spot, since the sun shines, the sky is blue, the sea (during summer) is calm and the scenery is very idyllic and romantic; therefore, there are periods of the year when the island is crowded. Second, Kefalonia is an island, and therefore, isolated from the mainland. Third, Kefalonia has many mountains, which hinders internal transportation.

Next, certain information about the island will be discussed that relates to this project. We will start by presenting some geographic data; we will talk about island terrain, ports, beaches, etc. Then, we will analyze the regional administration and the demographics of the island. Distinguishing between permanent and temporary residents (tourists). Following that, we will refer to modes of transportation, which is very important to our project. Finally, we will talk about the history of earthquakes in Kefalonia.

Figure 6. A poster of the movie Captain Corelli's Mandolin (From: GO Smell the Coffee, 2009)

B. GEOGRAPHY

Kefalonia is the largest of the Ionian Islands[1] in Western Greece (Figure 7). Argostoli is the island's capital. The island is located in the entrance of Patras' Gulf, north of Zakynthos, south of Lefkada and west of Ithaki (Figure 8). It has an area of 730 square kilometers and permanent population of 36,404 people (according to the census of 2001). The island's population will be analyzed later on.

The terrain of the island is mountainous, as shown in Figure 9. The mountain Ainos covers the largest part of the area. It is the highest mountain in the Ionian Islands, with a height of up to 1628 meters (Kefaloniainfo.com, n.d.).

[1] The Ionian Islands are a group of islands that are also known as the "Seven Islands" or "Heptanisa" (=Επτάνησα) due to the seven principal islands of the region. The group includes many smaller islands.

Figure 7. Greece – Kefalonia (From: Car Rental Kefalonia)

Figure 8. Ionian islands (From: Rhodes-Greece.info, n.d.)

The coast of Kefalonia forms many small gulfs and capes. The most important gulfs are the gulf of Sami, Myrto, Lourda, Athera, Fiscardo, Libadi, and Argostoli (also known as Koutavi). The most important capes (counter-clockwise, from the south) are Mounta, Kapros, Sarakiniko, Mitikas, Kentri, Dafnoudi, Atheras, Ortholithia, Skiza, Gerogompos, Akrotiri, Santa Pelagia, Liakas, Kastanas, etc.

Generally, the beaches of the west side of the island are rocky and abrupt; on the other hand, the beaches on the east side of the island are less abrupt. The beach Myrtos (on the northwest side) has been selected 11 times as the best Greek beach. The same beach has been characterized several times as the most beautiful beach in the Mediterranean and has been included on the list of the most beautiful beaches of our planet. On the west side of the island, there are a lot of beautiful beaches, such as Petana and Platia Ammos.

One of the main attractions of the island are the numerous caves, such as the caves of Melissani, Agkalaki, Saint Theodores, Zervati, Drogkarati, Sakkou, etc.

C. REGIONAL ADMINISTRATION - DEMOGRAPHIC ANALYSIS

The "*Kapodistrias Plan*" (as Statute 2539 of 1997 is called) has changed the administrative map of Greece. Under the plan, small communities have been connected under the same regional administration to create "new" municipalities. The objective of that plan was to improve public administration at the regional level and reduce the preexisting bureaucracy by reducing the number of mayors and town councils. Under that plan, Kefalonia has been divided into the following eight (8) municipalities (General Secretariat of the National Statistical Service of Greece, 2001; (Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)[2],

1. **Municipality of Argostoli** - came from the connection of the communities shown in Table 7. Its permanent population is 12,589. It has (General Secretariat of the National Statistical Service of Greece, 2010) an area of 152 square kilometers. The capital of Argostoli is the township of Argostoli, where the mayor and the municipality council are located.

2. **Municipality of Erissos -** came from the connection of the communities shown in Table 8. Its permanent population is 1,963. It has an area of 74 square kilometers. The capital of Erissos is the township of Vasilikadi, where the mayor and the municipality council are located.

3. **Municipality of Elios-Proni** - came from the connection of the communities shown in Table 9. Its permanent population is 2,840. It has an area of 112 square kilometers. The capital of Elios-Proni is the township of Pastra, where the mayor and the municipality council are located.

[2] The data of permanent population come from the census of 2001. Despite the fact that a long time has passed since then, and that it is believed that the permanent population of the island was increased (due to the fact that foreign immigrants moved to the island), we will use the data of 2001 census, since this is the only official available information.

4. **Municipality of Livathos -** came from the connection of the communities shown in Table 10. Its permanent population is 4,663. It has an area of 69 square kilometers. The capital of Livathos is the township of Ceramii, where the mayor and the municipality council are located.

5. **Municipality of Sami -** came from the connection of the communities shown in Table 11. Its permanent population is 2,895. It has an area of 130 square kilometers. The capital of Sami is the township of Sami, where the mayor and the municipality council are located.

6. **Municipality of Pilari -** came from the connection of the communities shown in Table 12. Its permanent population is 1,565. It has an area of 26 square kilometers. The capital of Pilari is the township of Santa Efimia, where the mayor and the municipality council are located.

7. **Municipality of Paliki** - came from the connection of the communities shown in Table 13. Its permanent population is 7,836. It has an area of 120 square kilometers. The capital of Paliki is the township of Lixouri, where the mayor and the municipality council are located.

8. **Community of Omala** - covers the center of the island. It has a permanent population of 1,053. It has an area of 47 square kilometers.

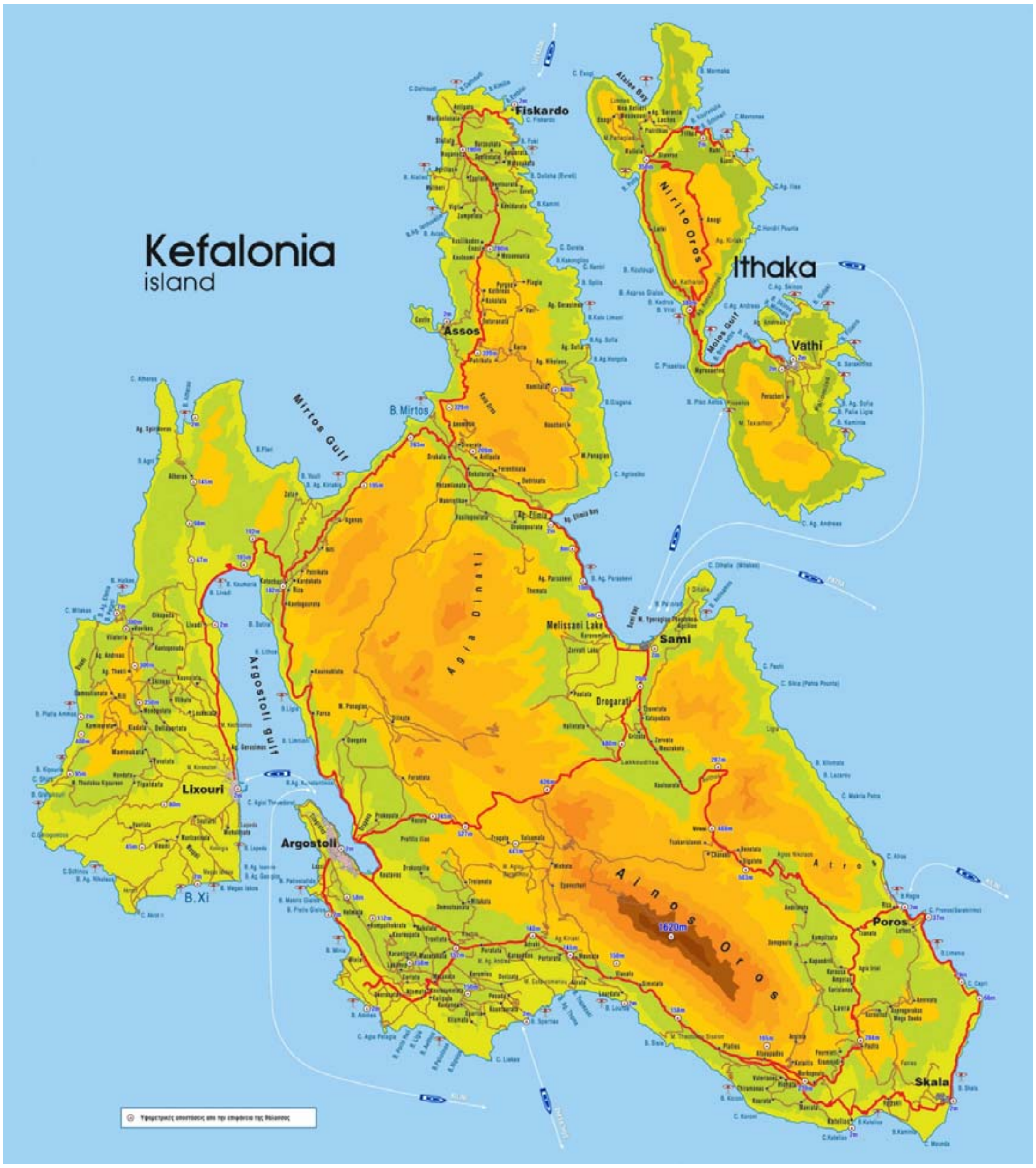

Figure 9. Detailed map of Kefalonia (From: Kefaloniainfo.com, n.d.)

Table 7. Population of Municipality of Argostoli

Communities	Population
Argostoli	9,522
Agonas	202
Davgata	128
Dilinata	739
Zoli	167
Thinea	362
Kourouclata	123
Nifio	96
Troianata	175
Faraclata	812
Farses	263
Total	**12,589**

Table 8. Population of Municipality of Erissos

Communities	Population
Vasilikiadi	150
Antipata di Erissos	209
Assos	122
Vareas	52
Karia	41
Korthea	133
Komitata	126
Messovounii	136
Neochori	56
Patricata	102
Plagiá	83
Touliata	306
Fiscardo	447
Total	**1,963**

Table 9. Population of Municipality of Elios – Proni

Communities	Population
Pastra	243
Santa Irini	363
San Nicola	181
Arginia	39
Valerianos	262
Marcoloulos	272
Mavrata	159
Xenopoulos	214
Poros	1,237
Skala	700
Chionata	170
Total	**3,840**

Table 10. Population of Municipality of Livathos

Communities	Population
Ceramii	379
Vlachata Ikosimias	728
Karavados	244
Lakithra	426
Lourdata	160
Metaxata	493
Mousata	197
Peratata	564
Pessada	327
Svoronata	674
Sparties	471
Total	**4,663**

Table 11. Population of Municipality of Sami

Communities	Population
Sami	1,223
Grisata	443
Karavomilos	342
Poulata	166
Pirgí	545
Chaliotata	176
Total	**2,895**

Table 12. Population of Municipality of Pilari

Communities	Population
Santa Efimia	635
Divarata	414
Makriotica	516
Total	**1,565**

Table 13. Population of Municipality of Paliki

Communities	Population
Lixouri	3,940
Santa Thecla	417
Atheras	217
Damoulianata	157
Kaminarata	347
Katogi	407
Kontogenada	154
Kouvalata	250
Monopolata	241
Rifio	68
Skinea	213
Soulari	440
Favarata	202
Chavdata	474
Chavriata	309
Total	**7,836**

The new regional administration map is shown in Figure 10. As shown, the island has been divided into eight regions. The same map shows the main roads that connect the capital of each municipality and the ports of the island. The communities (towns or villages) are connected with each other and their capital by narrow rural roads that are shown in Figure 9. For simplicity, we will assume that the supplies will be delivered at the capitals of each Municipality. The local administration will be responsible to deliver those supplies in every community of its region.

Figure 10. The regional administrative map (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

The above-mentioned population is characterized as permanent. As mentioned earlier, Kefalonia is a lovely island that attracts many visitors every year. The number of tourists staying in a hotel or camping could not be retrieved. The following method was used to calculate a rough estimate of visitors (General Secretariat of the National Statistical service of Greece, 2001):

- We found (General Secretariat of the National Statistical Service of Greece, 2008) [3] the capacity of hotels, similar establishments, and camping. The capacity was counted in number of available beds.
- We found the usage rate, per month, of beds in hotels and similar establishments.
- We put those data on an Excel sheet and found that the number of visitors ranges from 2692 to 8638. The results of that effort are shown in Table 14.

Table 14. Capacity and usage of hotels, similar establishments and tourists campsite per month in Kefalonia for year 2008

Month	***Number of Bed - Places***			**Use of bed-places**	**Estimated visitors**
	Hotels and similar establishments	**Tourist campsites**	**Total**		
January	9,402	1,197	10,599	25.40%	2,692
February	9,402	1,197	10,599	28.00%	2,967
March	9,402	1,197	10,599	34.30%	3,635
April	9,402	1,197	10,599	29.00%	3,073
May	9,402	1,197	10,599	48.70%	5,161
June	9,402	1,197	10,599	64.50%	6,836
July	9,402	1,197	10,599	76.40%	8,097
August	9,402	1,197	10,599	81.50%	8,638
September	9,402	1,197	10,599	67.50%	7,154
October	9,402	1,197	10,599	39.70%	4,207
November	9,402	1,197	10,599	29.50%	3,126
December	9,402	1,197	10,599	28.40%	3,010

[3] This information was retrieved from the General Secretariat of the National Statistical Service of Greece. The numbers posted in the site refer to the year 2008, and are for Kefalonia prefecture (including the island of Ithaca) as a whole. However, we decided to use these data because there wasn't available data for each island. Ithaca is smaller than Kefalonia, and the ratio between number of hotel beds of Kefalonia over number of hotel beds of Ithaca is 44:1; therefore, we assumed that the error wouldn't be significant.

From the above table, we conclude that people prefer to visit Kefalonia during the summer and in September.

D. TRANSPORTATION

Transportation information is divided into two categories: external and internal. External transportation refers to the available ways that may be used to travel to or from Kefalonia. Internal transportation is the available ways to move around Kefalonia.

1. External Transportation

As previously mentioned, the island has an airport and five harbors. The airport (Ministry of Infrastructure Transportation and Networks, n.d.) is located in the south part of the island, 10 kilometers away from the city of Argostoli. It started to operate in 1971. The airport has:

- One passenger terminal
- One fire fighting station, which provides category 6 fire protection (Airports Authority of India, 2010)[4]
- An 8,000 foot runway
- Aircraft parking area of 22,000 square meters

The distance of the airport of Kefalonia from other main airports of Greece is:

- Around 300 kilometers from the airports of Athens. The three main active airports of Athens are "Eleftherios Venizelos" International Airport, Elefsis Air Force Base and Megara Army airport (where the tactical airlift squadrons and helicopter squadrons are based).
- Around 75 kilometers from the Araxos and Andravida Air Force bases.

The island has five ports (Internetinfo.gr, n.d.) (Figure 8):

- Sami is the major port that links Kefalonia with Patras (Peloponnesos) and Ithaca
- Poros, in the south, has ferry routes to Kyllini (Peloponnesos)

[4] The level of protection provided at an airport for rescue and fire fighting will be based on the longest airplanes normally using the airport and their fuselage width. In accordance to that site, category 6 is referred to an airport that may host airplanes that have maximum length of 39m and maximum width fuselage of 5m.

- Argostoli, in the west, is the largest port, for local boats and ferries to Zakynthos and regularly to Lixouri
- Fiscardo, in the north, has links to Lefkada and Ithaca
- Lixouri is situated 5 km across the bay from Argostoli. There is a road connection to the rest of the island, but driving from Lixouri to Argostoli involves a 35 km detour

2. Internal Transportation

Kefalonia has an adequate road network that is restricted by the natural barrier of Mount Ainos. The road network is shown in detail in Figure 9. The main roads of the island are shown in Figure 10. The distances of the road routes between the main municipalities, the harbors and the airport of the island are shown in Table 15. Additionally, Table 16 shows the direct distances between those places.

Table 15. Distances (in km) of the road routes between the main municipalities, the harbors and the airport of Kefalonia

	Argostoli	**Vasilikiadi**	**Pastra**	**Ceramii**	**Sami**	**Santa Efimia**	**Lixouri**	**Omala**	**Poros**	**Fiscardo**	**Airport**
Argostoli	0	43	29	12	27	33	35	18	38	53	12
Vasilikiadi	43	0	58	53	30	22	42	43	55	10	52
Pastra	29	58	0	26	29	37	62	25	9	64	31
Ceramii	12	53	26	0	31	38	42	24	35	61	7
Sami	27	30	29	31	0	8	33	13	25	38	33
Santa Efimia	33	22	37	38	8	0	40	20	33	30	41
Lixouri (Only car / With ferry)	35 / 5	42 / 48	62 / 34	42 / 14	44 / 33	35 / 41	0	45 / 26	65 / 46.5	51 / 58.5	48 / 19.5
Omala	18	43	25	24	13	20	45	0	20	60	25
Poros	18	55	9	35	25	33	65	20	0	63	37
Fiscardo	53	10	64	61	38	30	51	60	63	0	60
Airport	10	52	31	7	33	41	48	25	37	60	0

Source is Google Earth

Apart from the road network, sea routes connect Kefalonia's harbors. The distances among the aforementioned harbors, and between them and Patras and Kyllini (two main harbors of Peloponnesos) are shown in Table 17. Of course, we should

mention that regular trade routes have not been established among the harbors of Kefalonia (except Argostoli and Lixouri); however, such sea routes may be used under special situations (such as transportation of supplies after an earthquake).

Table 16. Distances (in km) between the main municipalities, the harbors and the airport of Kefalonia

	Argostoli	Vasilikiadi	Pastra	Ceramii	Sami	Santa Efimia	Lixouri	Omala	Poros	Fiscardo	Airport
Argostoli	0	26.7	24.75	8.9	15.55	16.9	6.05	10.1	24.75	33.55	5.75
Vasilikiadi	26.7	0	38.95	32.47	19.35	12.65	25.8	26.15	34.5	5.4	32.85
Pastra	24.75	38.95	0	17.05	19.6	29.7	29.9	15.8	6.65	43.3	21.75
Ceramii	8.9	32.47	17.05	0	16.65	20.45	13.95	7.7	19.25	37.75	4.8
Sami	15.55	19.35	19.6	16.65	0	7.2	19.35	8.95	15.75	23.95	19.5
Santa Efimia	16.9	12.65	29.7	20.45	7.2	0	17.9	13.65	22.9	17.6	21.9
Lixouri	6.05	25.8	29.9	13.95	19.35	17.9	0	14.9	30.1	31.15	10.85
Omala	10.1	26.15	15.8	7.7	8.95	13.65	14.9	0	15.2	31.3	11.1
Poros	24.75	34.5	6.65	19.25	15.75	22.9	30.1	15.2	0	38.45	24
Fiscardo	33.55	5.4	43.3	37.75	23.95	17.6	31.15	31.3	38.45	0	38.35
Airport	5.75	32.85	21.75	4.8	19.5	21.9	10.85	11.1	24	38.35	0

Table 17. Distances (in km) between the Kefalonia's harbors and Peloponnesus harbors

	Sami	Poros	Argostoli	Fiscardo	Lixouri	Kyllini	Patras
Sami	0	25	85	25	82	67	100
Poros	25	0	60	50	58	42	87
Argostoli	85	60	0	74	5	80	137
Fiscardo	25	50	74	0	72	92	118
Lixouri	82	58	5	72	0	75	132

The distances refer to the sea routes except of the distance between Patras–Kyllini, which refers to the road route (Source Google Earth).

E. HISTORY OF ISLAND EARTHQUAKES

Kefalonia is just to the east of a major tectonic fault, where the European plate meets the Aegean plate at a slip boundary. This is similar to the more famous San Andreas Fault (on the west coast of the United States). There are regular earthquakes along this fault. Papazachos and Papazachou (2003) detailed the most important earthquakes that have taken place in Greece. In accordance with that book, during the last 500 years 19 major earthquakes have taken place in Kefalonia. The main parameters of these earthquakes are shown in Table 18. The epicenters of these earthquakes are shown in Figure 11. The earthquakes are summarized below:

1. The first (recorded) great earthquake took place during the spring of 1469. The epicenter of the earthquake was at 38.3^{o}N and 20.5^{o}E and the magnitude was 7.2. The settlement of the Saint George Castle collapsed and many people died. The earthquake was noticed on the mainland.

2. The second (recorded) great earthquake took place on 30 September 1636. The epicenter of the earthquake was at 38.1^{o}N and 20.3^{o}E and the magnitude was 7.2. According to two sources,[5,6] 525–540 people died, around 1,500 people were injured and the settlements of Saint George, Argostoli, Lixouri and Livathi collapsed. People abandoned their homes in the villages of Elios, Markopoulo, Valta, Koroni, Pirgi, Herakleio, and Solomata. Passing ships experienced large waves (tsunamis). Trees were eradicated and rocks fell from Mount Ainos; however, no damage was reported in the village of Omala. The aftershocks lasted until the spring of the following year.

3. The third (recorded) great earthquake took place on 16 July 1638. The epicenter of the earthquake was at 38.2^{o}N and 20.4^{o}E and the magnitude was 6.4. That earthquake completed the work of the previous great earthquake of 1636. It destroyed the buildings that remained after the previous earthquake.

[5] Letter of the Syndics (Mayors).

[6] Report of Ierotheos Abbatiou, written in 1648.

4. The fourth (recorded) great earthquake took place on 24 August 1658. The epicenter of the earthquake was at 38.2^oN and 20.4^oE and the magnitude was 7.0. In accordance to a report of the Doge of Venice, some 300 people died. The earthquake hit the Paliki Peninsula especially hard. 500 homes collapsed in Lixouri.

5. The fifth (recorded) great earthquake took place on 8 September 1714. The epicenter of the earthquake was at 38.1^oN and 20.5^oE and the magnitude was 6.4. Approximately 280 homes collapsed, and new hot springs were created.

6. The sixth (recorded) great earthquake took place on 23 June 1741. The epicenter of the earthquake was at 38.15^oN and 20.40^oE and the magnitude was 6.4. The earthquake destroyed the southwest part of the island; in particular, damage was reported in Lixouri, Argostoli and Saint George Castle. The aftershocks lasted for five months and caused additional damage to the west part of the island.

7. The seventh (recorded) great earthquake took on 13 June 1759. The epicenter of the earthquake was at 38.2^oN and 20.5^oE and the magnitude was 6.3. The source that described the earthquake was the diary of a monk and doesn’t provide many accurate data about the damages that it caused.

8. The eighth (recorded) great earthquake took place on 24 July 1766. The epicenter of the earthquake was at 38.1^oN and 20.4^oE and the magnitude was 7.0. Many homes and churches collapsed, approximately 20 people died and the smell of sulfur was noticed.

9. The ninth (recorded) great earthquake took place on 22 July 1767. The epicenter of the earthquake was at 38.3^oN and 20.4^oE and the magnitude was 7.2. Damage was reported mainly to the west part of the island. All the homes in Lixouri collapsed and around 50 people died. In all, 2,642 homes on the island collapsed, 2,946 were damaged and 253 people died. The aftershocks lasted until the summer of the following year.

10. The tenth (recorded) great earthquake took place on 14 March 1862. The epicenter of the earthquake was at 38.3^{o}N and 20.4^{o}E and the magnitude was 6.5. The earthquake destroyed Argostoli and caused damage in Lixouri.

11. The eleventh (recorded) great earthquake took place on 4 February 1867. The epicenter of the earthquake was at 38.39^{o}N and 20.52^{o}E and the magnitude was 7.4. The earthquake caused damage in the west part of the island. In Lixouri only two homes remained standing. Many villages were destroyed. In all, 2,612 homes collapsed, 2,946 were damaged and 224 people died. Additionally, after the earthquake a small tsunami was noticed.

12. The twelfth (recorded) great earthquake took place on 24 January 1912. The epicenter of the earthquake was at 38.11^{o}N and 20.67^{o}E and the magnitude was 6.8. The earthquake damaged mostly the southwest part of the island. The aftershocks lasted until April of the same year.

13. The thirteenth (recorded) great earthquake took place on 27 January 1915. The epicenter of the earthquake was at 38.36^{o}N and 20.60^{o}E and the magnitude was 6.6. The earthquake caused damage mostly in the northeast part of the island and the adjacent island of Ithaca.

14. The fourteenth (recorded) great earthquake took place on 7 August 1915. The epicenter of the earthquake was at 38.50^{o}N and 20.62^{o}E and the magnitude was 6.7. The earthquake caused damage mostly in the northeast part of the island and the adjacent island of Ithaca. Two tsunamis were also noticed. Their source was in the sea between Kefalonia and Lefkada. The tsunamis moved towards these islands.

15. The fifteenth (recorded) great earthquake took place on August 12th of 1953. The epicenter of the earthquake was at 38.30^{o}N and 20.80^{o}E and the magnitude was 7.2. Actually there was a series of earthquakes. Among them the greatest had magnitude 7.2. Those earthquakes caused great damage to the islands of Kefalonia,

Zakynthos, and Ithaca. Of the 33,300 homes of these islands, 27,659 collapsed, 2,780 were seriously damaged, and 2,394 were slightly damaged. Additionally, 455 people died, 21 disappeared, and 2,412 were injured.

16. The sixteenth (recorded) great earthquake took place on 10 April 1962. The epicenter of the earthquake was at 37.90^{o}N and 20.10^{o}E and the magnitude was 6.3. That earthquake occurred north of Zakynthos. However, it caused damage to Kefalonia as well.

17. The seventeenth (recorded) great earthquake took place on 6 July 1962. The epicenter of the earthquake was at 37.81^{o}N and 20.20^{o}E and the magnitude was 6.1. That earthquake occurred north of Zakynthos. However, it caused damage to Kefalonia as well.

18. The eighteenth (recorded) great earthquake took place on 17 September 1972. The epicenter of the earthquake was at 38.21^{o}N and 20.31^{o}E and the magnitude was 6.3. The earthquake caused damage to the southwest part of the island. 108 old homes suffered damage beyond repair. Additionally damage was noticed in 57 buildings and 2 bridges. Only 1 person was injured.

19. The nineteenth (recorded) great earthquake took place on 17 January 1983. The epicenter of the earthquake was at 38.10^{o}N and 20.20^{o}E and the magnitude was 7.0.

Table 18. The parameters of the greatest recorded earthquakes that harmed Kefalonia

O/N	Date	Coordinates		Magnitude	Intensity (MMI)	Human losses	Legend in Figure 11
1	Spring of 1469	38.30°N	20.50°E	7.2	IX	Unknown	a
2	30 Sep 1636	38.10°N	20.30°E	7.2	IX	525 – 540	b
3	16 Jul 1638	38.20°N	20.40°E	6.4	VIII	Unknown	c
4	24 Aug 1658	38.20°N	20.40°E	7.0	IX	300	d
5	8 Sep 1714	38.10°N	20.50°E	6.4	VIII	Unknown	e
6	23 Jun 1741	38.15°N	20.40°E	6.4	VIII	Unknown	f
7	13 Jun 1759	38.20°N	20.50°E	6.3	VIII	Unknown	g
8	24 Jul 1766	38.10°N	20.40°E	7.0	IX	20	h
9	22 Jul 1767	38.30°N	20.40°E	7.2	X	253	i
10	14 Mar 1862	38.30°N	20.40°E	6.5	IX	0	j
11	4 Feb 1867	38.39°N	20.52°E	7.4	X	224	k
12	24 Jan 1912	38.11°N	20.67°E	6.8	X	8	l
13	27 Jan 1915	38.36°N	20.60°E	6.6	IX	0	m
14	7 Aug 1915	38.50°N	20.62°E	6.7	IX	0	n
15	12 Aug 1953	38.30°N	20.80°E	7.2	X+	476	o
16	10 Apr 1962	37.90°N	20.10°E	6.3	VI	0	p
17	6 Jul 1962	37.81°N	20.20°E	6.1	V+	0	q
18	17 Sep 1972	38.21°N	20.31°E	6.3	VII	0	r
19	17 Jan 1983	38.10°N	20.20°E	7.0	VI	0	s

Papazachos, B., & Papazachou, K. (2003). The earthquakes of Greece. Athens: Ziti.

From the above description, we conclude the following:

1. From the 19 recorded great earthquakes, 9 earthquakes occurred in summer time (47.4%), 4 earthquakes occurred in winter time (21%), and 3 each occurred in autumn and in spring.

2. The linear relation, between the season of the year that the earthquake took place and its magnitude, was found to be weak (Coefficient Correlation ρ=-0.245)

3. The range of magnitudes of the earthquakes is between 6.1 and 7.4. The mean magnitude is 6.74, the median magnitude is 6.7 and the mode magnitude is 7.2. Furthermore, according to Louvari, Kiratzi, & Papazachos (1999) the Cephalonia

transform fault is considered capable of generating earthquakes with a maximum magnitude of 7.4, which is in accordance with the historical observations in Table 18.

4. The minimum period of time without an earthquake ranges from 3 months to 167 years. The average period of time without an earthquake is 28 years. The period of time between twelve earthquakes was less than 20 years.

5. The earthquakes' epicenters are located usually near the west and southwest part of the island. This is the reason that the southwest part of the island usually suffers the most serious damage.

6. In terms of macroseismic intensity, the most common earthquake intensity among the greatest 19 earthquakes in Kefalonia is IX (6 out of the 19 or 32%), and the maximum is X.

Figure 11. The epicenters of the 19 recorded great earthquakes of Kefalonia

Source Google Earth

V. MEANS OF TRANSPORTATION, TRANSPORTATION COSTS AND RELIEF ITEMS

A. INTRODUCTION

This chapter presents information on the available means of transportation, the costs of transporting the relief items to the locations where they are needed, and the assumptions and conditions for use of these means of transportation. We will also describe the different kinds of relief items required for a post-earthquake disaster response.

For this project, we decided to use three different modes of transportation: ground transportation with trucks using the available roads on the island, fixed-wing aircraft taking off from two airports and landing on the only airport in Kefalonia, and ships departing from the port of Patras (or one of the ports in Kefalonia) to deliver relief items to a port located in Kefalonia.

The destinations for the relief items are the ten main municipalities of Kefalonia: Argostoli, Vasilikadi, Pastra, Ceramii, Sami, Santa Efimia, Lixouri, Omala, Poros, Fiscardo, and the airport of Kefalonia. As the origin for the relief items we decided to use two logistic centers, one located in Athens and one located in Patras. The distances of these two logistics centers from the nearby airports/ports were considered to be negligible and were not accounted for (equal to zero); as a result, there was no cost assigned to the transportation of relief items from each of the logistics centers to adjacent airports or ports.

From the three airports of Athens that could be used (“Eleftherios Venizelos” International Airport, Elefsis Air Force Base, and Megara Army airport), we chose the Elefsis Air Force Base because it is a designated military airport with adequate facilities and size to accommodate this kind of operations. All the distances in the model are measured from the Elefsis Air Force Base, but in essence there would be no significant differences if any other airport in the Athens area were used.

From the two main ports on the west coast of Greece that could accommodate Kefalonia relief operations (Kyllini and Patras), we chose Patras due to its greater size and for slightly closer proximity to Athens, which is one of the logistics centers for relief items. As a result, all the distances in the transportation network are measured from Patras.

The relief items that will be transported in the affected area after an earthquake can be divided into three major categories: food and water items, non-perishable items like tents and cots, and medical supplies.

B. GROUND TRANSPORTATION

1. Military Trucks

Our research was focused on the types of military trucks currently in service in the Greek Armed Forces. Civilian trucks can be, and probably will be, used in this kind of disaster relief operation. However, as our research was focused on the technical characteristics of the trucks, a decision was made to limit to military trucks as that information is most readily attainable on them. The sources of information for this research were Jane’s website (Jane's, 2010) and the Hellenic Army’s website (Hellenic Army, 2010). Greece uses various types of military trucks obtained from multiple sources, some produced domestically, others bought internationally and many donated from the armed forces of other countries. The most critical information for this project is the number of vehicles in service (inventory), their age, dimensions, and maximum load capacity. This information is summarized in Table 19, where all relevant information that could be obtained is presented.

From the data presented in Table 19, we considered the ELBO 14 ME 14 8-ton truck as the most suitable for disaster relief operations, because it is available in sufficient numbers, has adequate capacity and is a relatively new vehicle, which means that there are enough vehicles in good condition to undertake the burden of a disaster relief operation. The rest of the vehicles in Table 19 were either old models (e.g., Steyr 680) or specialized off-road trucks (e.g., TATRA T815 and T815 VT 26.265), didn’t have a large

enough load capacity (e.g., IFA L60 LA/PVB), were not available in sufficient numbers, or there was not enough information on the number of vehicles currently in service.

Table 19. Greek military trucks currently in service (After: Jane's, 2010; Hellenic Army, 2010)

Vehicle type	Inventory	Max load capacity kg	Length (m)	Max speed in km/hr:	Range (km):
ELBO 14 ME 14	850	8,000	6.56	80	800
ELBO 14 ME 22	Supplied to Greece as the ELBO 14 ME 22 (approx. 80 delivered)	8,100	6.30	85	
IFA L60 LA/PVB	Donated by Germany unknown number in service	5,000	7.13	100	643
IVECO-Magirus	German Army surplus, unknown number in service	5,400	7.10	80	600
M35/M44A2	Small number in service	4,535	6.70	90	480
Oshkosh (MTVR)	73 between 2004-2006	13,608	9.82	105	483
Scania P113 HK	87	11,540	7.60	90	
Steyr 680 M (bulk of production between 1975 and 1980 concluded in 1985)	As of early 2003 an estimated 8,500 Steyr 680 vehicles of all types remained in service	5,170	6.57	80	450
Steyr 680 M3 (bulk of production between 1975 and 1980 concluded in 1985)	As of early 2003 an estimated 8,500 Steyr 680 vehicles of all types remained in service	5,500	6.73	80	500
TATRA T815 VVN.20.235 (ex-East German Army surplus)	Unknown number in service	10,500	8.39	90	1000
TATRA T815 VT 26.265 (ex-East German Army surplus)	Unknown number in service	14,900	9.28	86	1000

Remarks
1. Numbers presented in this table are the authors' best estimates.
2. Specifications do not include towed loads; speeds, range and loading are for on-road routes
Some information was not available for all vehicle types

Figure 12. Steyr 14 M 22 Truck (Similar to ELBO 14 ME 14) (From: Jane’s, 2010)

The vehicle’s speed was not considered critical since most of the roads on Kefalonia would not allow for a loaded truck to take advantage of high speeds. Also, the range was not considered critical since all the trucks in service have adequate range provided that they can be refueled once a day.

There are no military units on Kefalonia (Jane's, 2010), which means that the first trucks will have to be transported to the island on Roll-on/Roll-off (Ro-Ro) type ferries at the beginning of the relief operations while carrying their first load of relief items.

2. Cost for Ground Transportation

The transportation costs for items transported by the trucks were based on the Minister of National Defense’s decision for the pricing of government services for 2010 (Hellenic Government, 2010). This is in essence a price catalogue that specifies the prices the Hellenic Government charges for the use of government owned defense equipment. These prices are usually adjusted annually according to the recommendations of the General Staffs of the Air Force, Navy, and Army. This project used 2010 prices.

Although these costs are derived from calculations based on the previous fiscal year's expenses and fuel prices, and may not be completely accurate, they are the official Hellenic Government rates (Hellenic Government, 2010) and were considered accurate enough for the purposes of this project. The details on pricing, for the use of government trucks with a load capacity over 3.5 tons (per the Minister's decision), are presented in Table 20.

Table 20. Charges for government trucks with loading capacity over 3.5 tons (After: Hellenic Government, 2010)

For distances up to 50 km				
Fixed cost	1.67	€/ton	0.001670	€/kg
Variable cost (min)	0.040	€/ton-km	0.000040	€/kg-km
Variable cost (max)	0.045	€/ton-km	0.000045	€/kg-km
For distances greater than 50 km				
Fixed cost	1.79	€/ton	0.001790	€/kg
Variable cost (min)	0.040	€/ton-km	0.000040	€/kg-km
Variable cost (max)	0.047	€/ton-km	0.000047	€/kg-km

In the Minister's decision, there are fixed (per ton of truck capacity) and variable (per ton of truck capacity per km of distance) charges. Fixed and variable charges have two rates, a lower one for distances up to 50 km and a greater one for distances over 50 km. There is also a range of prices for the variable charges in each rate. We used the highest price for the variable charge in each rate to make our calculations for this project (0.045 and 0.047 Euros per ton per km, respectively). Using these prices as costs, and the distances in km of the road routes between the main municipalities, the harbors and the airport of Kefalonia (Table 15), we calculated the transportation cost per kg of transported relief item for each land route. The transportation costs when using 8-ton trucks for each route are presented in Table 21.

Table 21. Transportation costs in Euros per kg for each origin - destination pair using 8-ton trucks

	Destination													
Origin	**Athens airport**	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikiadi**	**Ceramii**	**Omala**	**Pastra**
Athens logistic center	**0**	0.0126	0.0112											
Patras logistic center		**0**	**0**											
Port of Fiscardo				**0**	0.0048	0.0046	0.0043	0.0030	0.0034	0.0042	0.0021	0.0047	0.0046	0.0048
Port of Poros				0.0048	**0**	0.0033	0.0025	0.0032	0.0028	0.0048	0.0044	0.0032	0.0026	0.0021
Airport of Kefalonia				0.0046	0.0033	**0**	0.0021	0.0035	0.0032	0.0038	0.0042	0.0020	0.0028	0.0031
Argostoli				0.0043	0.0025	0.0021	**0**	0.0032	0.0029	0.0032	0.0036	0.0022	0.0025	0.0030
Santa Efimia				0.0030	0.0032	0.0035	0.0032	**0**	0.0020	0.0035	0.0027	0.0034	0.0026	0.0033
Sami				0.0034	0.0028	0.0032	0.0029	0.0020	**0**	0.0032	0.0030	0.0031	0.0023	0.0030
Lixouri				0.0042	0.0048	0.0038	0.0032	0.0035	0.0032	**0**	0.0036	0.0036	0.0037	0.0047
Vasilikiadi				0.0021	0.0044	0.0042	0.0036	0.0027	0.0030	0.0036	**0**	0.0043	0.0036	0.0045
Ceramii				0.0047	0.0032	0.0020	0.0022	0.0034	0.0031	0.0036	0.0043	**0**	0.0028	0.0028
Omala				0.0046	0.0026	0.0028	0.0025	0.0026	0.0023	0.0037	0.0036	0.0028	**0**	0.0028
Pastra				0.0048	0.0021	0.0031	0.0030	0.0033	0.0030	0.0047	0.0045	0.0028	0.0028	**0**

Remarks:

1. All costs are in Euros per kg of transported load for the specified route (origin-destination pair)
2. The maximum variable cost was used for the calculations in the table, for both distances up to 50 km and distances more than 50 km
3. The distance from Athens logistics center to Araxos airport and Patra's port was measured in Google Earth and it is 230 and 300 km respectively
4. All other distances can be found in Table 15
5. Costs were calculated assuming that 8-ton trucks are used at full capacity (fully loaded in each route with 8 tons of cargo)

For the cost calculations in Table 21, we assumed that the trucks would always be fully loaded. Using 8-ton trucks but not loading them up to their capacity would lead to increased actual transportation costs if the unused excess capacity is still charged with a cost. If in practice the 8-ton trucks are not utilized to their capacity, then a smaller truck would be more appropriate, but in any case the point of the calculation was to derive an indicative transportation cost for each route per kg of transported relief item.

For the cost calculations in Table 22, we considered the cost of using an eight ton truck as always fixed for a specified distance, regardless if it is fully loaded or not. This is a more realistic approach for estimating the actual costs of using the trucks, but it also means that we have to take into account the integer number of shipments or truckloads for each origin-destination pair, instead of just quantities in kg. This would mean that in our model the decision variables would have to be the integer number of loads instead continuous numbers of quantities in kg, which would be appropriate when using the costs in Table 21.

Table 22. Transportation costs in Euros per load for each origin - destination pair using 8-ton trucks

	Destination													
Origin	**Athens airport**	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikiadi**	**Ceramii**	**Omala**	**Pastra**
Athens logistic center	**0**	100.8	89.6											
Patras logistic center		**0**	**0**											
Port of Fiscardo				**0**	38.4	36.8	34.4	24	27.2	33.6	16.8	37.6	36.8	38.4
Port of Poros				38.4	**0**	26.4	20	25.6	22.4	38.4	35.2	25.6	20.8	16.8
Airport of Kefalonia				36.8	26.4	**0**	16.8	28	26	30.4	33.6	16	22.4	24.8
Argostoli				34.4	20	16.8	**0**	25.6	23.2	25.6	28.8	17.6	20	24
Santa Efimia				24	25.6	28	25.6	**0**	16	28	21.6	27.2	20.8	26.4
Sami				27.2	22.4	25.6	23.2	16	**0**	25.6	24	24.8	18.4	24
Lixouri				33.6	38.4	30.4	25.6	28	25.6	**0**	28.8	28.8	29.6	37.6
Vasilikiadi				16.8	35.2	33.6	28.8	21.6	24	28.8	**0**	34.4	28.8	36
Ceramii				37.6	25.6	16	17.6	27.2	24.8	28.8	34.4	**0**	22.4	22.4
Omala				36.8	20.8	22.4	20	20.8	18.4	29.6	28.8	22.4	**0**	22.4
Pastra				38.4	16.8	24.8	24	26.4	24	37.6	36	22.4	22.4	**0**

Remarks:
1. All costs are in Euros per transported truckload (shipment) for the specified route (origin-destination pair)
2. The maximum variable cost was used for the calculations in the table, for both distances up to 50 km and distances more than 50 km
3. The distance from Athens logistics center to Araxos airport and Patra's port was measured in Google Earth and it is 230 and 300 km respectively
4. All other distances can be found in Table 15
5. Costs in this table were calculated assuming that the cost for the use of 8-ton trucks is the same regardless if the truck is fully loaded or not (fixed).

C. SURFACE (SEA) TRANSPORTATION

1. Ships

There are several scheduled sea routes that serve the island of Kefalonia. We decided to focus on commercial Ro-Ro ships able to carry wheeled cargo. These ships

can load and unload cargo in every port on the island, using only the available docking installations and roads, without any additional facilities (e.g., cranes). Cargo can be loaded on 8-ton trucks, which are then driven on the ship, transported to the island, and then driven off the ship to unload the cargo in a local warehouse for further distribution, or directly to the final area of need. These ships can also be used to deliver the trucks that will be needed to transport the relief items on the island.

There are two main shipping companies with frequent scheduled routes from the ports of Patras and Kyllini, serving Kefalonia, Ithaca, and other islands in the Ionian Sea. These companies are Strintzis Ferries and Ionian Ferries; their ships that are currently committed to Ionian Sea routes are presented in Table 23 (Ionian Ferries, 2010; Strintzis Ferries, 2009; Koefoed-Hansen, 2010). There are also other companies in Greece with routes to the Adriatic Sea (Greece-Italy), and of course several shipping companies serving routes in the Aegean Sea (Jane's Information Group, 2001-2010; Koefoed-Hansen, 2010). If needed, it is possible to divert additional Ro-Ro type ships to the disaster relief effort, preferably those deployed in the Adriatic Sea routes, which cross the Ionian Sea anyway, or even ships that are deployed in Aegean Sea routes. Diverting additional ships from Aegean Sea routes would be more difficult, at least in the first 72 hours of the post disaster period, because of the distance they will have to travel to reach the west coast of Greece, and the necessary rescheduling. We assume that commercial ships belonging to Strintzis Ferries and Ionian Ferries will be readily available to transport relief items to Kefalonia and to serve all of the island's ports, in the immediate post disaster period.

Given that the length of the ELBO 14 8-ton truck is 6.56m (Table 19) and assuming that the average length of a passenger car is 4.25 m, each truck is equal to about 1.5 cars. This is how the capacity of each Ro-Ro type ship was calculated in Table 23.

Table 23. Cargo capacity of the Ionian Sea RoRo type ferries, when carrying 8-ton trucks 6.56m long

Ship's name	Cruising speed (km/hr)	Cruising speed (kts)	Vehicle Capacity cars	Vehicle capacity trucks	Ton capacity when using 8-ton trucks	Information Retrieved from
Dionisios Solomos	35.17	19.00	360	240	1,920.00	Jane's website, www.ferry-site.dk
Eptanisos	36	19.50	265	177	1,413.33	Jane's, Strintzis lines websites
Ionian Star	32.4	17.50	340	227	1,813.33	Jane's website, www.ferry-site.dk
Ionis	34.26	18.50	92	61	490.67	Jane's website, www.ferry-site.dk
Kefalonia	38.9	21.00	220	147	1,173.33	Strintzis Lines website, www.ferry-site.dk
				Total	**6,810.67**	

Remarks

1. Information was obtained initially from Jane's website, and then cross-referenced with information from the shipping companies' websites.
2. Information not available in the sources mentioned above was obtained from www.ferry-site.dk, and it is based on observations and contributions from individuals.
3. Information obtained from www.ferry-site.dk was cross-referenced when additional sources were available.
4. The table contains some of the ferries used in Aegean Sea routes, and most of the ferries used in the Adriatic Sea and Ionian Sea routes, for which information was available online (in 28 Feb. 2010).
5. All ships in the table can carry both passengers and vehicles in closed compartments.
6. All ships are of the Ro-Ro type (roll in roll out), able to carry wheeled cargo, which is driven on and off the ship.
7. The average car length was considered as 4.25m
8. The truck length for the purposes of this project is 6.56m for the ELBO 14 ME 14 8,000 kg truck, so 1 truck is equal to 1.5 cars
9. These are all Ro-Ro type ships used in routes in the Ionian Sea

Figure 13. The Ionian Star Ro-Ro type ship (From: Ionian Ferries, 2010)

2. Cost for Surface Transportation

The transportation costs when using ships were obtained from the websites of the two shipping companies with routes in the Ionian Sea and are presented in Table 24. The calculations for the transportation costs per kg of relief item were based on the assumption that all cargo is transported on ELBO 14 ME 14 type 8-ton trucks.

At this point, we made a distinction between local and non-local (or internal and external) sea routes for the Kefalonia disaster relief operations. We defined as non-local, or external, all the sea routes originating from ports off Kefalonia, and as local, or internal, the ones among Kefalonia’s ports. We calculated the average cost per kg per km for all the routes in Table 24 except from the routes Route Sami-Ithaki (Vathy), and Route Sami-Ithaki (Pissaetos), and the average cost per kg per km for just these two routes. The sea routes from Kefalonia to Ithaca (Ithaki) are very short and their costs are more indicative of the transportation cost for local sea routes among Kefalonia's ports. The distinction between internal and external routes was made to take into account the increased cost of the longer routes, the presumably increased port related fees in the ports of Patras and Kyllini, and the use of smaller or larger ships with different fixed costs. The two average costs are presented in Table 25.

Table 24. Transportation costs in Euros per kg for each origin - destination pair using RoRo type ferries and 8-ton trucks (After: Ionian Ferries, 2010; Strintzis Ferries, 2009)

All costs in Euros	Cost	Cost per vehicle length (€/m)	Cost for the ELBO 14 ME 14 (6.56m in length)	Route in km*	Cost per kg per km
Ionian Ferries company					
Route Kyllini - Zakinthos					
Trucks cost per m of length	10.20	10.20	66.91	31.00	0.00026981
Kyllini - Kefalonia (Poros)					
Trucks cost per m of length	13.70	13.70	89.87	42.00	0.00036239
Kyllini - Kefalonia (Argostoli/Lixouri)					
Trucks cost per m of length	16.60	16.60	108.90	80.00	0.00043910
Strintzis Lines company					
Route Patra - Sami					
Cars of up to 4,25m in length	61.90	14.56	95.54	100.00	0.00038526
Route Patra - Ithaki					
Cars of up to 4,25m in length	61.90	14.56	95.54	104.00	0.00038526
Route Sami - Ithaki (Vathy)					
Cars of up to 4,25m in length	14.70	3.46	22.69	33.00	0.00009149
Route Sami - Ithaki (Pissaetos)					
Cars of up to 4,25m in length	15.90	3.74	24.54	11.40	0.00009896
Route Kyllini - Kefalonia (Poros)					
Cars of up to 4,25m in length	46.50	10.94	71.77	42.00	0.00028941

*****Distances for the sea routes were measured using Google Earth

Table 25. Average transportation costs for local and non-local sea routes in the Ionian Sea

Average cost per kg per km*	Euros
For non local ship routes (external)	0.0003552037
For local ship routes (internal)	0.0000952258

***All costs are calculated for Ro-Ro type ferries and 8-ton trucks carrying the relief items

Using the distinction between local and non-local sea routes, the costs in Table 25 and the distances in Table 17, we calculated the cost per kg of transported relief item for each of the sea routes (Table 26).

Table 26. Cost in Euros per kg for each origin - destination pair using Ro-Ro type ferries and 8-ton trucks

	Destination				
Origin	**Port of Fiscardo**	**Port of Poros**	**Argostoli**	**Sami**	**Lixouri**
Patras port	0.041914033	0.030902719	0.048662903	0.035520367	0.046886884
Port of Fiscardo	**0**	0.00476129	0.00704671	0.002380645	0.006856258
Port of Poros	0.00476129	**0**	0.005713548	0.002380645	0.005523097
Argostoli	0.00704671	0.005713548	**0**	0.008094194	0.000476129
Sami	0.002380645	0.002380645	0.008094194	**0**	0.007808516
Lixouri	0.006856258	0.005523097	0.000476129	0.007808516	**0**

Remarks
1. All costs are per kg for the specified route (origin-destination pair)
2. Routes originating from Patra's port are considered non-local or external (>=87km)

Table 27. Cost[1] in Euros per 8-ton load for each origin - destination pair using Ro-Ro type ferries and 8-ton trucks

	Destination				
Origin	**Port of Fiscardo**	**Port of Poros**	**Argostoli**	**Sami**	**Lixouri**
Patras port[2]	335.3	247.2	389.3	284.2	375.1
Port of Fiscardo	**0.0**	38.1	56.4	19.0	54.9
Port of Poros	38.1	**0.0**	45.7	19.0	44.2
Argostoli	56.4	45.7	**0.0**	64.8	3.8
Sami	19.0	19.0	64.8	**0.0**	62.5
Lixouri	54.9	44.2	3.8	62.5	**0.0**

1. All costs are per truckload (shipment) for the specified route (origin-destination pair)
2. Routes originating from Patra's port are considered non-local or external (>=87km)

For the cost calculations in Table 27, we assumed that the transportation of relief items is always going to happen using 8-ton trucks 6.56 m long. This way the transportation cost is always fixed per ship transported truck for a specified distance, regardless if the truck is fully loaded or not. This was done to provide a more accurate approach for estimating the actual costs of using the specified trucks and ships. As in the case of the cost calculations for land transportation, this also means that when using the costs in Table 27 we have to take into account the integer number of shipments or truckloads for each origin-destination pair, instead of just their weight.

D. AIR TRANSPORTATION

1. Fixed-Wing Aircraft

There are two types of cargo aircraft in the Greek Air Force that can be used in disaster relief operations: the C-130H and B variants, and the C-27J; details on the specifications and available number for each type can be found in Table 28. The C-130H and B variants are four-engine aircraft, while the C-27J is a smaller twin-engine aircraft (Jane's, 2010; Jane's Information Group, 2009; Jane's Information Group, 2009; Hellenic Air Force General Staff, 2010).

Table 28. Fixed-wing cargo aircraft of the Hellenic Air Force (After: Jane's Information Gr, 2009)

Aircraft Type	Inventory*	Max Payload		Max cruising speed		
		kg	lb	kts	mph	km/h
C-130H/B Hercules	15	19,356	42,673	325	374	602
C-27J Spartan	12	11,500	25,353	315	362	583

* All aircraft are stationed at Elefsis Air Force Base located near Athens

Hellenic Air Force C-130H Hercules aircraft

Hellenic Air Force C-27J Spartan aircraft

Figure 14. The Hellenic Air Force C-130H and C-27J aircraft (From: Hellenic Air Force, 2010)

2. Cost for Fixed-Wing Aircraft Transportation

The calculations for the transportations costs when using the C-130H/B or the C-27J were based on the information provided in the Minister of National Defense’s decision for the pricing of government services for 2010 (Hellenic Government, 2010). Table 29 has the flight hour cost for each type of aircraft (for 2010), according to the Minister’s decision (Hellenic Government, 2010). In the last column of Table 29, the cost

per kg of transported relief item per km was calculated, using the maximum payload and the maximum cruising speed (Table 28) for each type of aircraft to derive the distance it can cover within one hour, carrying the maximum payload.

Table 29. Flight hour costs and transportation costs for C-130H/B and C-27J aircraft (After: Hellenic Government, 2010)

Aircraft Type	Flight hour cost (Euros)	Transportation Cost* per kg per km (Euros)
C-130H/B Hercules	9,693.76	0.00083192
C-27J Spartan	5,484.80	0.00081808

*****The transportation cost per kg per km was calculated using the maximum payload and the maximum cruising speed (Table 28) for each type of aircraft to based on the distance it can cover within one hour, carrying the maximum payload.

Examining the last column in Table 29, one can notice that when taking into account the speed and load capacity for each type of aircraft the transportation cost differences (measured in euros per kg per km) are not significant (approximately 0.0008 Euros for both types), with the C-130 aircraft being slightly more expensive. For simplification, we decided to use only the C-130 type aircraft in this project. Table 30 lists the distances between the airports used for disaster relief operations in Kefalonia.

Table 30. Distances between airports

All distances in km	Athens airport*	Araxos airport	Airport of Kefalonia
Athens airport	**0**	190	300
Araxos airport	190	**0**	75

(Source: Distances were measured using Google Earth)

*****All distances from Athens' airport were measured from the Elefsis Air Force Base airport, located in Athens

Using the information in Tables 29 and 30, we calculated the transportation costs when using the C-130H/B aircraft, for each origin-destination. The results of these calculations are presented in Table 31.

In Table 32 we calculated the transportation cost per sortie for the C-130H/B, for each route. Once more we considered this alternative approach as more accurate for realistically estimating the transportation costs of using the C-130H/B aircraft. As in the cases of the previous cost calculations for land and sea transportation, this also means that when using the costs in Table 32 we have to take into account the integer number of shipments, or sorties, for each origin-destination pair, instead of the transported quantities in kg.

Table 31. Transportation costs* per transported kg when using C-130H/B aircraft

All costs are in euros per kg for the specified route (origin-destination pair)	Destination		
	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	**0**	0.15806429	0.24957519
Araxos airport	0.15806429	**0**	0.06239380

***All costs were calculated assuming the aircraft is loaded to capacity and traveling at maximum cruising speed

Table 32. Transportation costs* per load when using the C-130H/B aircraft

All costs are in euros per sortie for the specified route (origin-destination pair)	Destination		
	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	**0**	3,059.49	4,830.78
Araxos airport	3,059.49	**0**	1,207.69

***All costs were calculated assuming the aircraft is loaded to capacity and traveling at maximum cruising speed

3. Helicopters

The most suitable helicopter, in the Hellenic Armed Forces inventory, for transporting cargo is the CH-47D Chinook, an all-weather medium transport helicopter. Information on the Greek Army helicopters was retrieved from Jane's website (Jane's, 2010; Jane's Information Gr, 2010) and the Hellenic Army's website (Hellenic Army General Staff, 2010). Table 33 has the number of CH-47D in service in the Greek Army and the aircraft's specifications.

Table 33. Cargo helicopters of the Hellenic Army (After: Jane's, 2010; Jane's Information Gr, 2010)

Aircraft Designation	Inventory	Usable Cargo Volume		Max Payload		Max cruising speed		
		m^3	ft^3	kg	lb	kts	Mph	km/h
Chinook CH-47D*	17	42	1,474	12,284	27,082	140	161	259

***** All CH-47D are stationed in the Megara Attiki Army base, near Athens

Figure 15. The Hellenic Army CH-47D Chinook helicopter (From: Hellenic Army General Staff, 2010)

4. Cost for Helicopter Transportation

Once more, we used flight hour costs for the CH-47D found in the Minister of National Defense's decision for the pricing of government services for 2010 (Hellenic Government, 2010). Table 34 has the flight hour cost for the Hellenic Army Chinook helicopter (for 2010). In the last column of Table 34, the cost per kg of transported relief item per km was calculated, using the maximum payload and the maximum cruising speed (Table 30) for the CH-47D helicopter, to derive the distance it can cover within one hour, carrying the maximum payload.

Table 34. Flight hour costs and transportation costs* for CH-47D Chinook helicopter (After: Hellenic Government, 2010)

Aircraft Designation	Flight hour cost (Euros)	Transportation Cost per kg per km (Euros)
Chinook CH-47D	4,713.33	0.00148145

***** The transportation cost per kg per km was calculated using the maximum payload and the maximum cruising speed (Table 30) for the CH-47D to based on the distance it can cover within one hour, carrying the maximum payload.

Tables 16 and 28 have the distances between the locations of interest for the disaster relief operations in Kefalonia. These were measured using Google Earth and they are the distances in km. We used these distances and transportation cost per kg per km in Euros from Table 34 to calculate all costs in Table 35.

Table 35. Transportation costs* per kg when using CH-47D helicopters

All costs are in Euros per kg for the specified route (origin-destination pair)	**Athens airport**	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikiadi**	**Ceramii**	**Omala**	**Pastra**
Athens airport	**0**	0.28148	0.23851	0.39259	0.36147	0.44444	0.39999	0.38518	0.37925	0.40592	0.39259	0.38962	0.38222	0.36444
Araxos airport	0.28148	**0**	0.04444	0.12148	0.08444	0.11111	0.12296	0.11111	0.10370	0.12889	0.12000	0.11259	0.10666	0.08889
Patras port		0.04444	**0**											
Port of Fiscardo				**0**	0.05696	0.05681	0.04970	0.02607	0.03548	0.04615	0.00800	0.05592	0.04637	0.06415
Port of Poros				0.05696	**0**	0.03555	0.03667	0.03393	0.02333	0.04459	0.05111	0.02852	0.02252	0.00985
Airport of Kefalonia				0.05681	0.03555	**0**	0.00852	0.03244	0.02889	0.01607	0.04867	0.00711	0.01644	0.03222
Argostoli				0.04970	0.03667	0.00852	**0**	0.02504	0.02304	0.00896	0.03955	0.01318	0.01496	0.03667
Santa Efimia				0.02607	0.03393	0.03244	0.02504	**0**	0.01067	0.02652	0.01874	0.03030	0.02022	0.04400
Sami				0.03548	0.02333	0.02889	0.02304	0.01067	**0**	0.02867	0.02867	0.02467	0.01326	0.02904
Lixouri				0.04615	0.04459	0.01607	0.00896	0.02652	0.02867	**0**	0.03822	0.02067	0.02207	0.04430
Vasilikiadi				0.00800	0.05111	0.04867	0.03955	0.01874	0.02867	0.03822	**0**	0.04810	0.03874	0.05770
Ceramii				0.05592	0.02852	0.00711	0.01318	0.03030	0.02467	0.02067	0.04810	**0**	0.01141	0.02526
Omala				0.04637	0.02252	0.01644	0.01496	0.02022	0.01326	0.02207	0.03874	0.01141	**0**	0.02341
Pastra				0.06415	0.00985	0.03222	0.03667	0.04400	0.02904	0.04430	0.05770	0.02526	0.02341	**0**

***** All costs were calculated assuming the helicopter is loaded to capacity and traveling at maximum cruising speed

In Table 36, we calculated the transportation costs for each load (sortie) of relief items when using the CH-47 Chinook helicopter. As with the other means of transportation, we considered so far, this approach is another way for realistically estimating the transportation costs of using the CH-47 helicopter. Once more, when using the costs in Table 33, we have to take into account the integer number of shipments, or sorties, for each origin-destination pair, instead of the quantities in kg.

Table 36. Transportation costs* per load when using CH-47D helicopters

All costs are in Euros per load of 12,284 kg for the specified route (origin-destination pair)	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikiadi	Ceramii	Omala	Pastra
Athens airport	**0**	3,457.70	2,929.86	4,822.58	4,440.30	5,459.50	4,913.48	4,731.55	4,658.71	4,986.32	4,822.58	4,786.09	4,695.19	4,476.78
Araxos airport	3457.70	**0**	545.90	1,492.26	1,037.26	1,364.88	1,510.44	1,364.88	1,273.85	1,583.28	1,474.08	1,383.06	1,310.21	1,091.92
Patras port		545.90	**0**											
Port of Fiscardo				**0**	699.70	697.85	610.51	320.24	435.84	566.91	98.27	686.92	569.61	788.02
Port of Poros				699.70	**0.00**	436.70	450.45	416.80	286.59	547.74	627.84	350.34	276.64	121.00
Airport of Kefalonia				697.85	436.70	**0**	104.66	398.49	354.88	197.40	597.86	87.34	201.95	395.79
Argostoli				610.51	450.45	104.66	**0**	307.59	283.02	110.06	485.83	161.90	183.77	450.45
Santa Efimia				320.24	416.80	398.49	307.59	**0**	131.07	325.77	230.20	372.21	248.38	540.50
Sami				435.84	286.59	354.88	283.02	131.07	**0**	352.18	352.18	303.05	162.89	356.73
Lixouri				566.91	547.74	197.40	110.06	325.77	352.18	**0**	469.49	253.91	271.11	544.18
Vasilikiadi				98.27	627.84	597.86	485.83	230.20	352.18	469.49	**0**	590.86	475.88	708.79
Ceramii				686.92	350.34	87.34	161.90	372.21	303.05	253.91	590.86	**0**	140.16	310.29
Omala				569.61	276.64	201.95	183.77	248.38	162.89	271.11	475.88	140.16	**0**	287.57
Pastra				788.02	121.00	395.79	450.45	540.50	356.73	544.18	708.79	310.29	287.57	**0**

***** All costs were calculated assuming the helicopter is loaded to capacity and traveling at maximum cruising speed

E. COMPARISON OF TRANSPORTATION COSTS

As can be seen, we made several assumptions to calculate the transportation costs for the relief items, when using the different modes of transportation. The ultimate goal of this effort was not to have the most accurate, but rather to estimate an indicative or representative cost when using ships, helicopters or fixed-wing aircraft, based on information that was readily available on line, or could be obtained from official Hellenic Government sources. Table 33 has all the costs calculated for each transportation mode to make a direct comparison easier. The most expensive way to transport goods seems to be the CH-47D helicopter, and the cheapest is using trucks or ships, depending on the distance and route.

Even if in practice the actual costs are different than the ones we calculated in this chapter, the model's results (quantities of items transported by ship, aircraft, trucks, and helicopters) should not change (except from the total transportation cost), as long as the rank among the various costs remains the one depicted in Table 37.

The C-27J aircraft, although it is cheaper to operate (lower flight hour cost) has a reduced load capacity, and the transportation cost per kg per km is not that different from the bigger C-130H/B. The choice for either aircraft depends on the desired capacity. If the C-130H/B for any reason cannot be used efficiently (e.g., the relief items in the logistics centers are not available in large quantities during the first 72 post-disaster hours, and as a result it is not possible to load the aircraft up to their maximum capacity for each flight), then the C-27J would be a better choice.

Another conclusion from the cost comparison in Table 37 is that the results also seem intuitively correct, since the helicopter is the most expensive means of transportation, followed by fixed-wing aircraft. We were also expecting trucks and ships to be the cheapest way to carry relief items.

Table 37. Comparison of transportation costs* (per kg)

Rank	Means of Transportation	Lowest	Highest
1	**Helicopter CH-47**	0.0014815	0.001481
2	**C-130H/B**	0.0008319	0.000831
3	**C-27J**	0.0008181	0.000818
4	**Sea routes using Ro-Ro ferries and 8-ton trucks (6.56m length)**	0.0000952	0.000355
5	**Land Routes using 8-ton trucks (6.56m length)**	0.0000548	0.000283

*****

- All costs are in Euros per kg of cargo per km of distance transported
- The cost for Ro-Ro ferries is the average cost for external routes (Highest column) and internal routes (Lowest column).
- The highest transportation cost when using trucks is for the Kefalonia airport to Ceramii route (7km)
- The lowest transportation cost when using trucks is for the Araxos airport to Athens logistics center route (230km)

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VI. THE RELIEF ITEMS

A. INTRODUCTION

The major sources of information for this chapter were the Sphere Project "Humanitarian Charter and Minimum Standards in Disaster Response" handbook (The Sphere Project, 2004) and Valerie McCall's 2006 Master's Thesis at NPS titled "Designing and prepositioning humanitarian assistance pack-up kits (HA PUKs) to support Pacific Fleet emergency relief operations" (McCall, 2006).

The Sphere project is a program launched in 1997, by a group of humanitarian Non-Governmental Organizations (NGOs), the Red Cross and the Red Crescent Movement, with the purpose of developing a set of universal minimum standards for humanitarian assistance. The "Humanitarian Charter and Minimum Standards in Disaster Response" was the result of this team effort and contains minimum standards in water supply, sanitation, hygiene, food, nutrition, shelter, security, and many other areas of interest to humanitarian assistance.

McCall's thesis dealt with the prepositioning of humanitarian assistance pack-up kits containing relief items that are commonly used in disaster relief or humanitarian assistance operations. McCall has included in her thesis an analytical description of the composition of these kits, and the specifications of their individual relief items.

In this project, we used the information from McCall's thesis for the weight of selected materials from the HA PUKs to calculate the total weight for the relief items per person, except for the drinking water. Since we deal with the first 72 post-disaster hours, we decided that bottled water will be used to satisfy the drinking requirements of the affected population, instead of water purification systems as suggested in McCall's thesis. Since Kefalonia is an island, seawater could be possibly used for some sanitation purposes, or fresh water for sanitation purposes could be transported to the island using tanker ships from the nearby ports of Patras and Kyllini in a few hours.

We chose to deal with the distribution of three major categories of relief items: (1) food and water, (2) medical supplies, and (3) non-perishable materials such as cots, tents and blankets, hygiene kits, etc. Some of the relief materials have a periodic demand (e.g., food and water), while others only depend on the size of the affected population and do not have a periodic demand (e.g., tents).

B. FOOD AND DRINKING WATER

Table 37 describes the humanitarian daily ration and the necessary planning factor.

Table 38. Food requirements (From: McCall, 2006, Appendix C)

Description	Weight per daily ration kg	Planning factor
Humanitarian Daily Ration	1.179	1 daily ration per person per day

Table 39 describes the basic survival water needs, per person. The need for drinking water is specified as 2.5-3 liters per person per day.

Table 39. Simplified basic survival water needs (From: The Sphere Project, 2004, p. 64)

Basic Survival Water Needs per Person		
Survival needs: water intake (drinking and food)	2.5-3 liters per day	Depends on: the climate and individual physiology
Basic hygiene practices	2-6 liters per day	Depends on: social and cultural norms
Basic cooking needs	3-6 liters per day	Depends on: food type, social as well as cultural norms
Total basic water needs	7.5-15 liters per day	

Table 40 has information on water density for two different temperatures. Water density varies with temperature, but the variation is not significant and for the purposes

of this project we will always consider water density to be equal to 1 kg/lt (or 62.416 lb/ft^3) (United States Geological Survey, 2010b). This means that for our calculations 1lt of drinking water will always weigh 1kg.

Table 40. Fresh water density (From: USGS, 2010b)

Temperature		Water density	
F	**C**	**lb/ft^3**	**kg/lt**
32	0	62.416	1.000
100	38	61.998	0.993

C. MEDICAL SUPPLIES

We based the requirements for medical supplies on the medical category of relief items in an HA PUKs. Table 41 has the information on the weight and the planning factor for medical supplies.

Table 41. Medical supplies (From: McCall, 2006, Appendix C)

Description	Total Weight per Kit (kg)	Planning factor
WHO* Interagency Emergency Health Kit - Basic Unit	45.36	1 kit per 1000 people
WHO Interagency Emergency Health Kit - Supplemental Unit	453.59	1 kit per 10,000 people
Blanket, Casualty (Box of 288)	45.36	1 blanket per casualty, or 1 kit per 576 casualties

*WHO: World Health Organization

D. OTHER MISCELLANEOUS RELIEF ITEMS

This category includes all relief items that do not fall under the food, water, or medical supply categories. These are items related to shelter, sanitation, mortuary, and hygiene. Once more, we relied on McCall's thesis for information related to the characteristics and the planning factors for these items given in Table 42.

Table 42. Other non-perishable relief items (From: McCall, 2006, Appendix C)

Description	Weight per Item (kg)	Planning factor
Shelter		
Blanket, Bed 66" x 84"	0.151	1 per person
Cot	9.072	1 per person
Pillow	0.907	1 per person
Pillow case	0.378	1 per person
Sheet, Bed	1.966	1 per person
Sanitation		
Latrine: Grey Privacy Tent	3.629	1 per 20 people
Latrine: Commode, Field	13.608	1 per 20 people (each commode includes daily restroom kit for 20 people/3 days) toilet paper, towelette and bags for 20 people/5 days
Latrine: Restroom kit, disp	0.181	
Latrine: Can, waste receptacle, 32 gallon with lid	13.608	1 per latrine and 1 per 100 people
Trash bags	0.065	1/person/day and 20/latrine/day
16 quart bucket (laundry)	0.907	1 per 10 people
Laundry soap	0.567	1 per person
Mortuary		
Pouch, Human Remains	3.629	1 per casualty
Hygiene kit	2.044	1 kit per person
Toothbrush	0.019	1 per person
Toothpaste	0.151	1 per person
Comb	0.025	1 per person
Soap, toilet 5 oz	0.145	1 per person
Soap dish	0.076	1 per person
Shampoo	0.907	1 per person
Pad, sanitary (feminine hygiene) 28 pack	0.032	1 per person
Razor	0.008	1 per person
Deodorant	0.151	1 per person
Towel	0.076	1 per person
Personal Washcloth	0.454	1 per person

E. GENERAL REMARKS ON THE RELIEF ITEMS

Project Sphere's handbook (2004) and McCall (2006) provide substantial information for planning and preparing humanitarian assistance operations. Our primary purpose was to use this information to establish a reasonable basis for the quantities of relief materials in terms of kg per person. We did not use the whole HA PUK, but we used the weight of specific materials contained in an HA PUK, and converted everything to kg per person. Tables 43–46 have the final results of these calculations for all the supplies in Tables 38, 39, 41, and 42.

Table 43. Requirements in non-perishable items

Non periodical demand	Quantity in kg Per person
Shelter - Common Items all Climates	12.47
Sanitation - All Climates	2.40
Hygiene kit	2.044
Total	**16.92**

Table 44. Requirements in medical supplies

Non periodical demand	Quantity in kg Per person
WHO Interagency Emergency Health Kit - Basic Unit	0.045
WHO Interagency Emergency Health Kit - Supplemental Unit	0.045
Total	**0.091**

Table 45. Requirements in items for casualties

Non periodical demand	Quantity in kg Per casualty
Mortuary	3.63
Blanket, Casualty (Box of 288)	0.079
Total	**3.707**

Table 46. Requirements in food and water

Periodical demand	Quantity in kg Per person per day
Food	1.18
Water	3
Total	**4.18**

VII. THE MODELS

A. INTRODUCTION

Effective and efficient humanitarian relief depends on logistics, which includes delivery of emergency supplies and services (Salmeron, Apte, 2009). Therefore we model the transfer of commodities (such as food, water, medicine and other non-perishable items) from the logistics centers[7] of large Greek cities (Athens and Patras) to demand points on the stricken island for the relief of the residents to optimize the relief effort. Such a model deals with distribution of goods from supply points (sources) to points of demand (destinations). Those goods may be transported directly from the origins to the destinations, or through specific points (transshipment) where shipments arrive and leave (Balakrishnan, Render, & Stair, 2007). This may happen because there is no established direct transportation method between the origin and the destination; or, the earthquake caused such damage to the infrastructure of the island that the established direct transportation method could not be used. For example, a port's wharf (which is a destination) is destroyed and the ships cannot unload their shipments in that port. In such case, the demand of that destination will be covered with shipments from other points of the island.

In disaster relief operations the priority is to maintain human lives. However, resources are scarce and therefore effort should be made to limit the transportation costs. Practice has shown that it may be possible to achieve cost savings by consolidating shipments from several sources through transshipment points. This type of approach is the basis for the hub-and spoke system of transportation utilized by most major U.S. airlines (Balakrishnan, Render, & Stair, 2007).

[7] The logistics centers are imaginable points that they are assumed to be the gathering points for the commodities that will be shipped to Kefalonia.

In case of a disaster relief operation, the objective is to schedule the transfer of goods from sources to the destination points within a specific time period and in a way that transportation costs are minimized. Therefore, the employment of a transshipment model seems most appropriate for the specific problem.

B. DESCRIPTION OF THE NETWORK

To illustrate the relationship of the sources, transshipment points and destinations, a network flow diagram is necessary. Even though the specific problem is a large real-world problem that requires a complicated diagram, Figure 16 is a fair representation.

From the diagram the following are implied:

- Two logistics centers will be used (orange nodes). The first is placed in Athens and the second is placed in Patras.
- Six transshipment points will be used; three of them are placed on the mainland (Athens airport, Araxos airport and the port of Patras), they are the blue nodes. The other three are placed on the island (airport of Kefalonia and the ports of Fiscardo and Poros) and they are the green nodes.
- The eight destinations are the capitals of the municipalities (pink nodes) where the commodities should be received. The eight destinations may be used as transshipment points as well.
- Four different transportation methods will be used, reflected by different colored arcs:
    - Red arcs for the ground transportation, using military 8-ton trucks
    - Blue arcs for the airlifts using fixed-wing aircraft of the Hellenic Air Force (C-130H/B)
    - Green arcs for the airlifts using helicopters of the Hellenic Army (CH-47 Chinooks)
    - Orange arcs for the sea transportation using the ferryboats that cover the local routes
- Due to the complexity of the diagram, the unidirectional (i.e., flow in only one direction) arcs are reflected by continuous lines and the bidirectional (i.e., flow in either direction) arcs by discontinuous lines (instead of having a pair of unidirectional arcs).

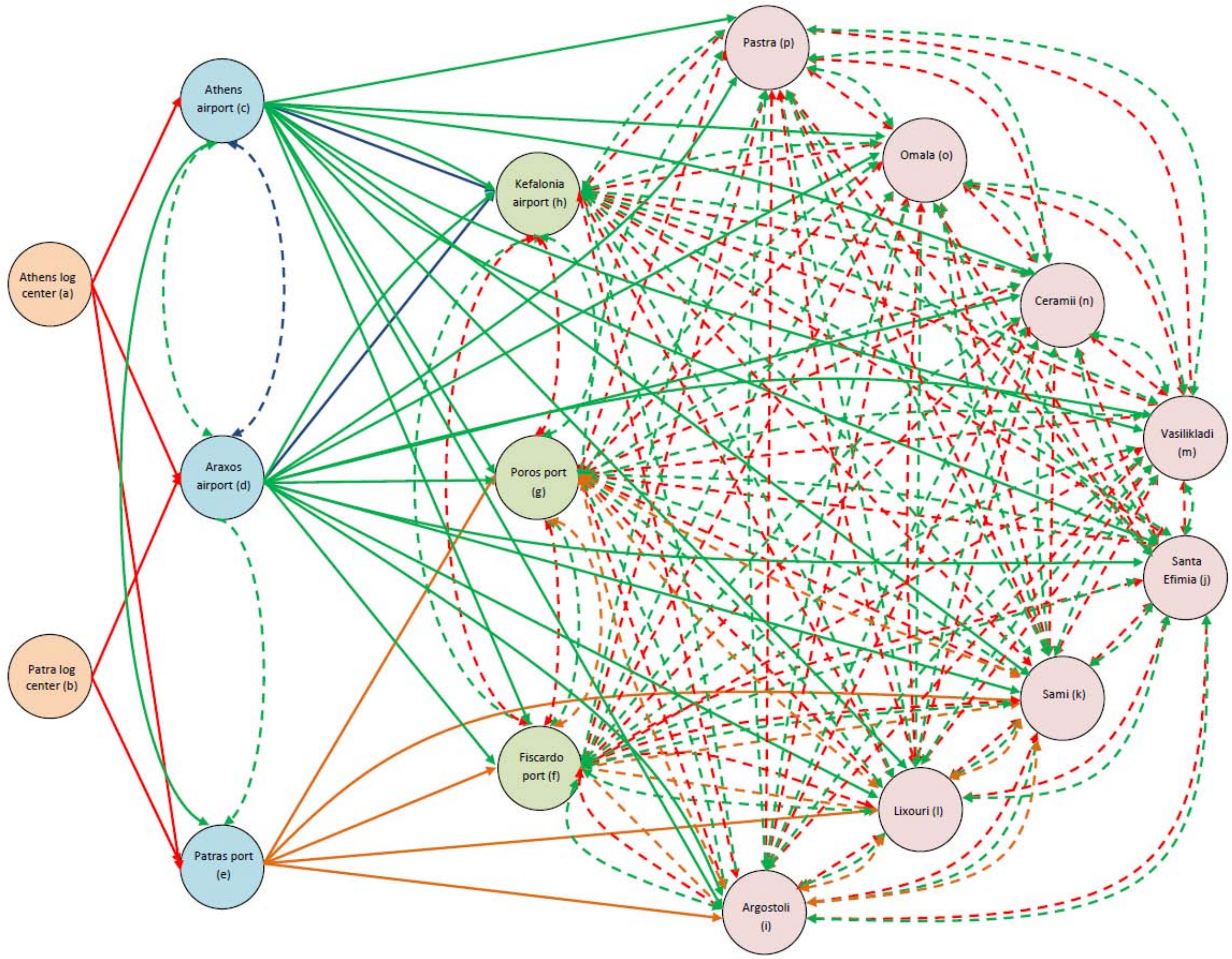

Figure 16. Graphic representation of the transportation network

Legend of Figure 16

Terrestrial transportation – One way

Terrestrial transportation – Both ways

Airlift (fixed wing aircraft) - One way

Airlift (fixed wing aircraft) - Both ways

Airlift (helicopter) - One way

Airlift (helicopter) - Both ways

Sea transportation - One way

Sea transportation - Both ways

Logistics center

Transshipment point (mainland)

Transshipment point (Kefalonia)

Final destination

C. DESCRIPTION OF NETWORK NODES AND ARCS

Before describing the nodes and the arcs of the network, we should note the following (Balakrishnan, Render, & Stair, 2007, Chapter 5):

> ... many network models share some common characteristics, as follows:
>
> In all network models, the decision variables represent the amounts of flows or shipments that occur in the network...
>
> There will be a flow balance constraint written for each node in the network. Those balance constraints calculate the net flow at each node (i.e., the difference between the total flow on all arcs entering a node and the total flow on all arcs leaving the node)...

With this in mind, we decided to develop a model (the first) where each arc of our network diagram reflects the masses (measured in kilograms) of commodities that are transferred between two points. The main assumption in this model is that the transportation cost is related to the masses of commodities that are transferred. Therefore, the model won't take into consideration the number of shipments that will be required in order to transfer those masses of commodities.

So, it is obvious that this model may suggest an optimal solution when in reality, for example a helicopter sortie is required to transfer a quantity of relief items that is less than half the capacity of the helicopter. Such decisions infer that the first model may not be realistic and may underestimate the time of response or the total transportation costs. Due to that weakness we decided to develop a second model, where each arc (of our network diagram) reflects the number of shipments that are transferred between two points.

In the first model, three types of mass flow are considered:

- Flow of food and water
- Flow of medicine
- Flow of other than perishable items

Since the model selects the mass flow between two different points (source, transshipment point or destination), these flows are considered decision variables; in this

first model the decision variables are non-negative real numbers. Since there are 158 arcs (35 unidirectional and 123 bidirectional), and each unidirectional arc reflects three decision variables while each bidirectional arc reflects six decision variables, it is concluded that there are 843 decision variables.

In the second model, one type of shipment is considered. Therefore, the decision variables are the number of shipments between two different points; in this second model the decision variables are integers. Since there are 158 arcs (35 unidirectional and 123 bidirectional), and each unidirectional arc reflects one decision variable while each bidirectional arc reflects two decision variables, it is concluded that there are 281 decision variables.

We will use the following three different types of nodes:

- Origins: where we assume that the total flow on all arcs leaving each one of them will be less than or equal to 60% of the total demand for food and water, medicine and other than perishable items. Using this assumption assures that the demand will be covered from both logistic centers and that no wasteful relief commodities will be sent.
- Transshipment points: where we assume that the total flow entering all arcs will be equal (or greater) to the total flow leaving all arcs. Therefore, the net flow of those nodes will be zero (or greater). Using this assumption assures that there will remain no relief commodities on these nodes.
- Destinations: where we assume that the total flow entering all arcs, minus the total flow leaving all arcs, will be equal to the demand of the destinations themselves.

D. DESCRIPTION OF THE FIRST MODEL

1. Decision Variables

As we mentioned above they are 843 decision variables in the first model. The variables are divided into the following four types:

- Variables that describe the mass (=M) transferred by trucks (they are noted with letters TR (=trucks) followed by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $TRM_{sender-receiver}^{type-of-items}$. There are 345 decision variables of this type.
- Variables that describe the mass (=M) transferred by air using a fixed-wing aircraft (they are noted with letter FA (fixed-wing aircraft), followed by

indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $FAM_{sender-receiver}^{type-of-items}$. There are 12 decision variables of this type.

- Variables that describe the mass (=M) transferred by air using a helicopter (they are noted with letter HE (=helicopter), followed by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $HEM_{sender-receiver}^{type-of-items}$. There are 411 decision variables of this type.
- Variables that describe the mass (=M) transferred by sea (they are noted with letters SE (=sea), follow by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $SEM_{sender-receiver}^{type-of-items}$. There are 75 decision variables of this type.

As we mentioned above, three types of items will be transferred. Those items will be noted as follows:

- FW: Food and water
- ME: Medicine
- TB: Non-perishable items (such us tents, beds, blankets, etc.)

The locations of the sender and receiver will be noted as follows:

- a: Athens logistic center
- b: Patras logistic center
- c: Athens airport
- d: Araxos airport
- e: Patras port
- f: Port of Fiscardo
- g: Port of Poros
- h: Airport of Kefalonia
- i: Argostoli
- j: Santa Efimia
- k: Sami
- l: Lixouri
- m: Vasilikadi
- n: Ceramii

- o: Omala
- p: Pastra

2. Objective Function

The objective function for this model seeks to minimize the total transportation cost. The objective function is expressed as the product of the mass of each type of item being transferred and the cost (per kg) of that transfer. The costs of each transfer per kg were shown in Tables 21, 26, 31, and, 35 of Chapter V. Those tables provide the coefficients of the objective function for a case where no earthquake has happened. Such a case is defined as the base line of the first model. The optimal solution of that may be used for comparison with the optimal solutions of the earthquake scenarios.

As we mentioned before, for each scenario the routes that cannot be used due to damages to the infrastructure (for example, a damaged road) will be assigned a very large transportation cost (10,000 € per kilogram). By doing so, we expect that the model will use this route as a last resort. The transportation costs (and, therefore, the particular coefficients of the objective functions) for each earthquake scenario will be discussed in the next chapter.

3. Constraints

The constraints are distinguished into two categories. The first category includes the flow balance requirement for each node and the second type includes the capacity of the available transportation means.

a. Flow Balance Constraints

As we discussed above, we need one flow balance constraint for each node in the network. Therefore three types of these constraints exist. We have:

- Demand constraints: there are 24 constraints that deal with the final destination demands, since we have 8 final destinations and each destination demands three types of relief commodities. The demand calculations follow.
- Constraints from the transshipment points: there are 18 constraints, since we have 6 transshipment points and each destination demands three types of relief commodities. For those nodes we are assuming that the net flow will be greater or equal to 0.

- Supply constraints: there are 6 constraints that deal with the final destination demands, since we have 2 sources and each destination demands three types of relief commodities.

The mathematical notation for the constraints is:

1) Equations for the Final Destination

(i) Covering Demand on Pastra:

$$\sum_{x_p,\mathrm{ITEM}} \mathrm{HEM}_{x_p p}^{\mathrm{ITEM}} - \sum_{x_p,\mathrm{ITEM}} \mathrm{HEM}_{p x_p}^{\mathrm{ITEM}} + \sum_{y_p,\mathrm{ITEM}} \mathrm{TRM}_{y_p p}^{\mathrm{ITEM}} - \sum_{y_p,\mathrm{ITEM}} \mathrm{TRM}_{p y_p}^{\mathrm{ITEM}} \geq \mathrm{D}_p^{\mathrm{ITEM}}$$

Where x_p is the destination (or origin) index from (or to) Pastra by helicopters (c, d, h, g, f, o, n, m, j, k, l and i), y_p is the destination (or origin) index from (or to) Pastra by trucks (h, g, f, o, n, m, j, k, l and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(ii) Covering Demand on Omala:

$$\sum_{x_o,\mathrm{ITEM}} \mathrm{HEM}_{x_o o}^{\mathrm{ITEM}} - \sum_{x_o,\mathrm{ITEM}} \mathrm{HEM}_{o x_o}^{\mathrm{ITEM}} + \sum_{y_o,\mathrm{ITEM}} \mathrm{TRM}_{y_o o}^{\mathrm{ITEM}} - \sum_{y_o,\mathrm{ITEM}} \mathrm{TRM}_{o y_o}^{\mathrm{ITEM}} \geq \mathrm{D}_o^{\mathrm{ITEM}}$$

Where x_o is the destination (or origin) index from (or to) Omala by helicopters (c, d, h, g, f, p, n, m, j, k, l and i), y_o is y_p is the destination (or origin) index from (or to) Omala by trucks (h, g, f, p, n, m, j, k, l and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(iii) Covering Demand on Ceramii:

$$\sum_{x_n,\mathrm{ITEM}} \mathrm{HEM}_{x_n n}^{\mathrm{ITEM}} - \sum_{x_n,\mathrm{ITEM}} \mathrm{HEM}_{n x_n}^{\mathrm{ITEM}} + \sum_{y_n,\mathrm{ITEM}} \mathrm{TRM}_{y_n n}^{\mathrm{ITEM}} - \sum_{y_n,\mathrm{ITEM}} \mathrm{TRM}_{n y_n}^{\mathrm{ITEM}} \geq \mathrm{D}_n^{\mathrm{ITEM}}$$

Where x_n is the destination (or origin) index from (or to) Ceramii by helicopters (c, d, h, g, f, p, o, m, j, k, l and i), y_n is the destination (or origin) index from (or to) Ceramii by trucks (h, g, f, p, o, m, j, k, l and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(iv) Covering Demand on Vasilikadi:

$$\sum_{x_m,\mathrm{ITEM}} \mathrm{HEM}_{x_m m}^{\mathrm{ITEM}} - \sum_{x_m,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{m}x_m}^{\mathrm{ITEM}} + \sum_{y_m,\mathrm{ITEM}} \mathrm{TRM}_{y_m m}^{\mathrm{ITEM}} - \sum_{y_m,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{m}y_m}^{\mathrm{ITEM}} \geq \mathrm{D}_m^{\mathrm{ITEM}}$$

Where x_m is the destination (or origin) index from (or to) Vasilikadi by helicopters (c, d, h, g, f, p, o, n, j, k, l and i), y_m is the destination (or origin) index from (or to) Vasilikadi by trucks (h, g, f, p, o, n, j, k, l and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(v) Covering Demand on Santa Efimia:

$$\sum_{x_j,\mathrm{ITEM}} \mathrm{HEM}_{x_j j}^{\mathrm{ITEM}} - \sum_{x_j,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{j}x_j}^{\mathrm{ITEM}} + \sum_{y_j,\mathrm{ITEM}} \mathrm{TRM}_{y_j j}^{\mathrm{ITEM}} - \sum_{y_j,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{j}y_j}^{\mathrm{ITEM}} \geq \mathrm{D}_j^{\mathrm{ITEM}}$$

Where x_j is the destination (or origin) index from (or to) Santa Efimia by helicopters (c, d, h, g, f, p, o, n, m, k, l and i), y_n is the destination (or origin) index from (or to) Santa Efimia by trucks (h, g, f, p, o, n, m, k, l and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(vi) Covering Demand on Sami:

$$\sum_{x_k,\mathrm{ITEM}} \mathrm{HEM}_{x_k k}^{\mathrm{ITEM}} - \sum_{x_k,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{k}x_k}^{\mathrm{ITEM}} + \sum_{y_k,\mathrm{ITEM}} \mathrm{TRM}_{y_k k}^{\mathrm{ITEM}} - \sum_{y_k,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{k}y_k}^{\mathrm{ITEM}} + \sum_{z_k,\mathrm{ITEM}} \mathrm{SEM}_{z_k k}^{\mathrm{ITEM}} - \sum_{z_k,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{k}z_k}^{\mathrm{ITEM}} \geq \mathrm{D}_k^{\mathrm{ITEM}}$$

Where x_k is the destination (or origin) index from (or to) Sami by helicopters (c, d, h, g, f, p, o, n, m, j, l and i), y_k is the destination (or origin) index from (or to) Sami by trucks (h, g, f, p, o, n, m, j, l and i), z_k is the destination (or origin) index from (or to) Sami by sea (g, f, l, and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(vii) Covering Demand on Lixouri:

$$\sum_{x_l,\mathrm{ITEM}} \mathrm{HEM}_{x_l l}^{\mathrm{ITEM}} - \sum_{x_l,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{l}x_l}^{\mathrm{ITEM}} + \sum_{y_l,\mathrm{ITEM}} \mathrm{TRM}_{y_l l}^{\mathrm{ITEM}} - \sum_{y_l,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{l}y_l}^{\mathrm{ITEM}} + \sum_{z_l,\mathrm{ITEM}} \mathrm{SEM}_{z_l l}^{\mathrm{ITEM}} - \sum_{z_l,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{l}z_l}^{\mathrm{ITEM}} \geq \mathrm{D}_l^{\mathrm{ITEM}}$$

Where x_l is the destination (or origin) index from (or to) Lixouri by helicopters (c, d, h, g, f, p, o, n, m, j, k and i), y_l is the destination (or origin) index from (or to) Lixouri by trucks (h, g, f, p, o, n, m, j, k and i), z_l is the destination (or origin) index from (or to) Lixouri by sea (g, f, k, and i), and ITEM is the type of relief items transferred (FW, ME or TB).

(viii) Covering Demand on Argostoli:

$$\sum_{x_i,\mathrm{ITEM}} \mathrm{HEM}_{x_i i}^{\mathrm{ITEM}} - \sum_{x_i,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{i}x_i}^{\mathrm{ITEM}} + \sum_{y_i,\mathrm{ITEM}} \mathrm{TRM}_{y_i i}^{\mathrm{ITEM}} - \sum_{y_i,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{i}y_i}^{\mathrm{ITEM}} + \sum_{z_i,\mathrm{ITEM}} \mathrm{SEM}_{z_i i}^{\mathrm{ITEM}} - \sum_{z_i,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{i}z_i}^{\mathrm{ITEM}} \geq \mathrm{D}_i^{\mathrm{ITEM}}$$

Where x_i is the destination (or origin) index from (or to) Argostoli by helicopters (c, d, h, g, f, p, o, n, m, j, k and l), y_i is the destination (or origin) index from (or to) Argostoli by trucks (h, g, f, p, o, n, m, j, k and l), z_i is the destination (or origin) index from (or to) Argostoli by sea (g, f, k, and l), and ITEM is the type of relief items transferred (FW, ME or TB).

2) Equations for the Intermediate Destinations

(i) Transportation of Relief Items Through Poros' Port:

$$\sum_{x_g,\mathrm{ITEM}} \mathrm{HEM}_{x_g g}^{\mathrm{ITEM}} - \sum_{x_g,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{g}x_g}^{\mathrm{ITEM}} + \sum_{y_g,\mathrm{ITEM}} \mathrm{TRM}_{y_g g}^{\mathrm{ITEM}} - \sum_{y_g,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{g}y_g}^{\mathrm{ITEM}} + \sum_{z_g,\mathrm{ITEM}} \mathrm{SEM}_{z_g g}^{\mathrm{ITEM}} - \sum_{z_g,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{g}z_g}^{\mathrm{ITEM}} \geq 0$$

Where x_g is the destination (or origin) index from (or to) Poros by helicopters (c, d, h, i, f, p, o, n, m, j, k and l), y_g is the destination (or origin) index from (or to) Poros by trucks (h, i, f, p, o, n, m, j, k and l), z_g is the destination (or origin) index from (or to) Poros by sea (i, f, k, and l), and ITEM is the type of relief items transferred (FW, ME or TB).

(ii) Transportation of Relief Items Through Port of Fiscardo:

$$\sum_{x_f,\mathrm{ITEM}} \mathrm{HEM}_{x_f f}^{\mathrm{ITEM}} - \sum_{x_f,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{f}x_f}^{\mathrm{ITEM}} + \sum_{y_f,\mathrm{ITEM}} \mathrm{TRM}_{y_f f}^{\mathrm{ITEM}} - \sum_{y_f,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{f}y_f}^{\mathrm{ITEM}} + \sum_{z_f,\mathrm{ITEM}} \mathrm{SEM}_{z_f f}^{\mathrm{ITEM}} - \sum_{z_f,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{f}z_f}^{\mathrm{ITEM}} \geq 0$$

Where x_f is the destination (or origin) index from (or to) Fiscardo by helicopters (c, d, h, i, g, p, o, n, m, j, k and l), y_f is the destination (or origin) index from (or to) Fiscardo by trucks (h, i, g, p, o, n, m, j, k and l), z_f is the destination (or origin) index from (or to) Fiscardo by sea (i, g, k, and l), and ITEM is the type of relief items transferred (FW, ME or TB).

(iii) Transportation of Relief Items Through Airport of Kefalonia:

$$\sum_{x_h,\mathrm{ITEM}} \mathrm{HEM}_{x_h h}^{\mathrm{ITEM}} - \sum_{x_h,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{h}x_h}^{\mathrm{ITEM}} + \sum_{y_h,\mathrm{ITEM}} \mathrm{TRM}_{y_h h}^{\mathrm{ITEM}} - \sum_{y_h,\mathrm{ITEM}} \mathrm{TRM}_{\mathrm{h}y_h}^{\mathrm{ITEM}} + \sum_{u_h,\mathrm{ITEM}} \mathrm{FAM}_{u_h h}^{\mathrm{ITEM}} \geq 0$$

Where x_h is the destination (or origin) index from (or to) airport of Kefalonia by helicopters (c, d, f, i, g, p, o, n, m, j, k and l), y_h is the destination (or origin) index from (or to) airport of Kefalonia by trucks (f, i, g, p, o, n, m, j, k and l), u_h is the or origin index to airport of Kefalonia by fixed wings airplane (c and d), and ITEM is the type of relief items transferred (FW, ME or TB).

(iv) Transportation of Relief Items Through Airport of Athens:

$$\mathrm{TRM}_{ac}^{\mathrm{ITEM}} + \mathrm{HEM}_{dc}^{\mathrm{ITEM}} - \sum_{x_c,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{c}x_c}^{\mathrm{ITEM}} + \mathrm{FAM}_{dc}^{\mathrm{ITEM}} - \sum_{u_c,\mathrm{ITEM}} \mathrm{FAM}_{\mathrm{c}u_c}^{\mathrm{ITEM}} \geq 0$$

Where x_c is the destination index from airport of Athens by helicopters (h, d, f, i, g, p, o, n, m, j, k and l), u_c is the destination index from airport of Athens by fixed wings airplane (h and d), and ITEM is the type of relief items transferred (FW, ME or TB).

(v) Transportation of Relief Items Through Airport of Araxos:

$$\sum_{x_d,\mathrm{ITEM}} \mathrm{HEM}_{x_d d}^{\mathrm{ITEM}} - \sum_{x'_d,\mathrm{ITEM}} \mathrm{HEM}_{\mathrm{d}x'_d}^{\mathrm{ITEM}} + \sum_{y_d,\mathrm{ITEM}} \mathrm{TRM}_{y_d d}^{\mathrm{ITEM}} + FAM_{cd}^{ITEM} - \sum_{u_d,\mathrm{ITEM}} \mathrm{FAM}_{du_d}^{\mathrm{ITEM}} \geq 0$$

Where x_d is the origin index to airport of Araxos by helicopters (c and e), x'_d is the destination index from airport of Araxos by helicopters (c, d, f, i, g, p, o, n, m, j, k and l), y_d is the destination index from airport of Araxos by trucks (a and b), u_d is the destination index from airport of Araxos by fixed wings airplane (c and h), and ITEM is the type of relief items transferred (FW, ME or TB).

(vi) Transportation of Relief Items Through Patras' Port:

$$\sum_{x_e,\mathrm{ITEM}} \mathrm{HEM}_{x_e e}^{\mathrm{ITEM}} - \mathrm{HEM}_{\mathrm{ed}}^{\mathrm{ITEM}} + \sum_{y_e,\mathrm{ITEM}} \mathrm{TRM}_{y_e e}^{\mathrm{ITEM}} - \sum_{z_e,\mathrm{ITEM}} \mathrm{SEM}_{\mathrm{ez}_e}^{\mathrm{ITEM}} \geq 0$$

Where x_e is the origin index to Patras' port by helicopters (c and d), y_e is the origin index to Patras' port by trucks (a and b), z_e is the destination index from Patras' port by sea (g, f, k, and l), and ITEM is the type of relief items transferred (FW, ME or TB).

3) Equations of the Starting Points:

(i) Getting Relief Items from Athens' Log Center:

$$TRM_{ac}^{ITEM} + TRM_{ad}^{ITEM} + TRM_{ae}^{ITEM} \leq 0.6 \times \sum_{d_a, ITEM} D_{d_a}^{ITEM}$$

Where d_d is the final destination index (i, j, k, l, m, n, o, and p) and ITEM is the type of relief items transferred (FW, ME or TB).

(ii) Getting Relief Items from Patras' Log Center:

$$TRM_{bd}^{ITEM} + TRM_{be}^{ITEM} \leq 0.6 \times \sum_{d_b, ITEM} D_{d_b}^{ITEM}$$

Where d_d is the final destination index (i, j, k, l, m, n, o, and p) and ITEM is the type of relief items transferred (FW, ME or TB).

The numerical coefficients of the above mentioned constraints are shown in Tables 47, 48, 49, and, 50. These coefficients are based on the modes of transportation on which are the same for all scenarios of the model. Those coefficients are the same for every type of item transferred (food, water, medicine, etc.). In those

tables, bidirectional arcs have two numbers (the first defines the outflows of the origin node of the arc and the second defines the inflows of the origin node of the arc), while unidirectional nodes have one number.

Table 47. Coefficients for sea transportation constraints of the first model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	1	1	1	1	1
Port of Fiscardo	0	-1/1	-1/1	-1/1	-1/1
Port of Poros	-1/1	0	-1/1	-1/1	-1/1
Argostoli	-1/1	-1/1	0	-1/1	-1/1
Sami	-1/1	-1/1	-1/1	0	-1/1
Lixouri	-1/1	-1/1	-1/1	-1/1	0

Table 48. Coefficients for airlift (using fixed-wing aircraft) constraints of the first model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	1	1
Araxos airport	1	0	1

The demand of each final destination is calculated as follows. From the data presented in Chapter VI, we concluded that for each person on the island it will be necessary to transport the following masses of relief commodities for three days:

- 4.179 kg of food and water per person
- 0.091 kg of medicine per person
- 16.92 kg of other than perishable items per person

Table 49. Coefficients for truck transportation constraints of the first model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	1	1	1											
Patras Logistic center		1	1											
Port of Fiscardo				0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Port of Poros				-1/1	0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Airport of Kefalonia				-1/1	-1/1	0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Argostoli				-1/1	-1/1	-1/1	0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Santa Efimia				-1/1	-1/1	-1/1	-1/1	0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Sami				-1/1	-1/1	-1/1	-1/1	-1/1	0	-1/1	-1/1	-1/1	-1/1	-1/1
Lixouri				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0	-1/1	-1/1	-1/1	-1/1
Vasilikadi				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0	-1/1	-1/1	-1/1
Ceramii				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0	-1/1	-1/1
Omala				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0	-1/1
Pastra				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0

Table 50. Coefficients for airlift (using helicopters) constraints of the first model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport	**0**	1	1	1	1	1	1	1	1	1	1	1	1	1
Araxos airport	1	**0**	1	1	1	1	1	1	1	1	1	1	1	1
Patras port		1	**0**											
Port of Fiscardo				**0**	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Port of Poros				-1/1	**0**	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Airport of Kefalonia				-1/1	-1/1	**0**	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Argostoli				-1/1	-1/1	-1/1	**0**	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Santa Efimia				-1/1	-1/1	-1/1	-1/1	**0**	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
Sami				-1/1	-1/1	-1/1	-1/1	-1/1	**0**	-1/1	-1/1	-1/1	-1/1	-1/1
Lixouri				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	**0**	-1/1	-1/1	-1/1	-1/1
Vasilikadi				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	**0**	-1/1	-1/1	-1/1
Ceramii				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	**0**	-1/1	-1/1
Omala				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	**0**	-1/1
Pastra				-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	**0**

We assumed that the earthquake takes place during the summer since, which is a plausible occurrence since 9 out of 19 times the earthquake occurred in summer. Using the data in Chapter IV, we assume that the population distribution on the island will be as shown in Table 51. Multiplying the population of each municipality by the masses of relief commodities required per person for three days, we calculate the demands for each municipality. These demands are shown in Table 52.

Table 51. Distribution of island population

Municipality	Permanent Population	Tourists	Total island population
Argostoli	12,589	2,939	15,528
Elios-Proni	3,840	897	4,737
Erissos	1,963	458	2,421
Livathos	4,663	1,089	5,752
Paliki	7,836	1,830	9,666
Pilari	1,565	365	1,930
Sami	2,895	676	3,571
Omala	1,053	246	1,299
Sum	**36,404**	**8,500**	**44,904**

Since we have assumed that each logistics center will contribute relief commodities it is implied that either supply center will provide up to 60% of the total demand mass as shown in Table 53.

b. Transportation Means Capacity Constraints

Our model presumes that the transportation of the relief commodities must be completed within specific time limits (3 days from the time that the earthquake happened) using specific resources. Therefore, we need a fourth type of constraints that will incorporate the restriction of time and the number of available transportation means. In that type of constraint we will take into consideration:

- The number of each type of vehicle (trucks, fixed wing airplanes, helicopters and boats) that we can use (available vehicles)
- The maximum load capacity (in kilograms) that each type of vehicle can transfer
- The cruise (or the economy) speed (kilometers per hour) that ships and trucks move
- The maximum number of hours per day that each type of vehicle can be used. For example, aircrafts and helicopters should be inspected at least at the beginning and the end of each day. Additionally, helicopters can land during night only in airports or in helipads.
- The average number of sorties that an aircraft (helicopter or fixed-wing airplane) may perform per day of operations and the average duration of each sortie. The average duration of each sortie includes the required time to load and unload the aircraft.

Table 52. Demand for relief items (in kg) for the Kefalonia municipalities (first model)

	Demand in kg
Demand on Pastra for food and water	19,794
Demand on Pastra for medicine	431
Demand on Pastra for non-perishable items	80,143
Demand on Omala for food and water	5,427
Demand on Omala for medicine	118
Demand on Omala for non-perishable items	21,976
Demand on Ceramii for food and water	24,036
Demand on Ceramii for medicine	523
Demand on Ceramii for non-perishable items	97,319
Demand on Vasilikadi for food and water	10,118
Demand on Vasilikadi for medicine	220
Demand on Vasilikadi for non-perishable items	40,969
Demand on Lixouri for food and water	40,392
Demand on Lixouri for medicine	879
Demand on Lixouri for non-perishable items	163,542
Demand on Sami for food and water	14,923
Demand on Sami for medicine	324
Demand on Sami for non-perishable items	60,420
Demand on Santa Efimia for food and water	8,067
Demand on Santa Efimia for medicine	175
Demand on Santa Efimia for non-perishable items	32,662
Demand on Argostoli for food and water	64,893
Demand on Argostoli for medicine	1413
Demand on Argostoli for non-perishable items	262,740
Total Demand for food and water	**187,654**
Total Demand for Medicine	**4,086**
Total Demand for Other than perishable items	**759,776**
Total mass to be shipped	**951,504**

Table 53. Supply of relief items (in kg) from the logistic centers

	Supply in kg
Getting Food and Water from Athens log center	**112,590**
Getting medicine from Athens log center	**2,450**
Getting non-perishable items from Athens log center	**455,863**
Getting Food and Water from Patras log center	**112,590**
Getting medicine from Patras log center	**2,450**
Getting non-perishable items from Patras log center	**455,863**

The above assumptions will provide us with the capacity of each type of vehicle for the period of the available 3 days after the earthquake. The capacity restrictions of each type of truck and ship should be less than or equal to the sum of the product of the shipment (in kg) that will be transferred through each route times the distance of each route. The capacity restrictions for the airlifts should be less than or equal to the masses (in kg) of items that can be transported given the above assumptions.

We now discuss the constraints:

a. Capacity of trucks in the mainland (Athens–Patras routes). We are expecting that 10 (8-ton) trucks will be used for item transportation, out of the 850 that the Armed Forces have in their inventory, for an earthquake relief operation. We assume that each truck will be available for 12 hours per day (we assume that a truck is not going to be available 24 hours per day because time is required for driver rest, loading and unloading, etc.). As was mentioned in Chapter V, the average speed of such trucks is 60 km per hour. Therefore, the capacity of the trucks that may be used will be 172,800,000 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route. Those coefficients are shown in Table 54.

Table 54. Distances (in km) of the road routes between mainland destinations

From/To	Athens airport	Araxos airport	Patras port
Athens logistic center	5	230	200
Patras logistic center	N/A	5	5

b. We are expecting that 10 (8-ton) trucks will be used for item transportation on the island, out of the 850 that the Armed Forces have in their inventory, for an earthquake relief operation. We assume that each truck will be available for 12 hours per day (we assume that a truck is not going to be available 24 hours per day because time is required for the driver rest, loading and unloading, etc.). As was mentioned in Chapter V, the average speed of such trucks is 35 km per hour. Therefore, the capacity of the trucks that may be used will be 100,800,000 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route. Those coefficients are shown in Table 15 of Chapter IV.

c. We are expecting that 2 ships, of the 5 that are operating in the Ionian Islands, will be used for an earthquake relief operation. Each ship may transport 1,362,133 kg. We assume that each ship will be available for 12 hours per day (we assume that a ship is not going to be available 24 hours per day because time is required to load and unload, etc.). As was mentioned in Chapter V, the average speed of such ships is 35 km per hour. Therefore, the capacity of the ships that may be used will be 3,466,509,466 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route. Those coefficients are shown in Table 17 of Chapter IV.

d. We are expecting that 2 C-130 aircraft, of the 15 in the Hellenic Air Force inventory, will be used for an earthquake relief operation. Each aircraft may transport 19,356 kg (load capacity). We assume that each aircraft will be available for 12 hours per day (we assume that an aircraft is not going to be available 24 hours per day because time is required for the crew to rest and for maintenance activities). Within those

12 hours, an airplane can perform 8 sorties of 1.5 hours per sortie. Therefore, the capacity restriction of the aircraft will be defined as the mass of items that may be transferred, calculated as the product of the load capacity of the aircraft per sortie and the number of sorties for the three days of operations. So the restriction capacity of the aircraft will be 929,088 kg. The coefficient of the decision variables for those restrictions will be 1 (if there is established route) and 0 (if there is no established route). Established routes are the routes between the three airports.

e. We are expecting that 4 CH-47 helicopters, of the 17 that the Hellenic Army has in its inventory, will be used for an earthquake relief operation. Each helicopter may transport 12,284 kg (load capacity). We assume that each aircraft will be available for 12 hours per day (we assume that an aircraft is not going to be available 24 hours per day because time is required for the crew to rest and for maintenance activities). Within those 12 hours, an airplane can perform 8 sorties of 1.5 hours per sortie. Therefore, the capacity restriction of the aircraft will be defined as the mass of items that may be transferred and is calculated as the product of the load capacity of the aircraft per sortie and the number of sorties for the three days of operations. So the restriction capacity of the aircraft will be 1,179,264 kg. The coefficient of the decision variables for those restrictions will be 1 (if the route is possible) and 0 (if the route is not possible). Since helicopters can land (almost) anywhere we assume that all coefficients are 1.

The mathematical notation used to define these constraints follows:

1) Quantities of Relief Items Transported Using Trucks for Routes on the Island

$$\sum (TRM_{qr} \times RL_{qr}) \leq (PH \times Hr_{TR}^{Isl} \times S_{TR}^{Isl} \times N_{TR}^{Isl} \times CTR)$$

Where CTR is the capacity of the truck,

q (origin index) and r (destination index) are f, g, h, I, j, k, l, m, n, o, p

RL_{qr} is the length of the land route in km from origin node q to destination node r

PH is the planning horizon in days

S_{TR}^{Isl} is the average speed for the trucks on the island routes

N_{TR}^{Isl} is the number of trucks doing the transportation on the island

2) Quantities of Relief Items Transported Using Trucks for Routes off the Island

$$\sum(TRM_{qr} \times RL_{qr}) \leq (PH \times Hr_{TR}^{Mnl} \times S_{TR}^{Mnl} \times N_{TR}^{Mnl} \times CTR)$$

Where CTR is the capacity of the truck,

q (origin index) and r (destination index) are c, d, e

RL_{qr} is the length of the land route in km from origin node q to destination node r

PH is the planning horizon in days

S_{TR}^{Mnl} is the average speed for the trucks on mainland routes

N_{TR}^{Mnl} is the number of trucks doing the transportation on the island

3) Quantities of Relief Items Transported Using Ships

$$\sum(SEM_{qr} \times SEL_{qr}) \leq (PH \times Hr_{SE} \times S_{SE} \times N_{SE} \times CTR)$$

Where CTR is the capacity of each truck loaded on ships,

q (origin index) and r (destination index) are f, g, I, k, l

SEL_{qr} is the length of the sea route in km from origin node q to destination node r

PH is the planning horizon in days

S_{SE} is the average speed for the ships

N_{SE} is the number of ships doing the transportations

4) Quantities of Relief Items Transported Using Helicopters

$$\sum(HEM_{qr}) \leq (PH \times SRT_{HE} \times CHE \times N_{HE})$$

Where CHE is the capacity of the helicopter,

q (origin node index) and r (destination node index) are c, d, e, f. g. h, i, j, k, l, m, n, o, p

PH is the planning horizon in days

SRT_{HE} is the average number of sorties per helicopter per day

N_{HE} is the number of available helicopters

5) Quantities of Relief Items Transported Using Fixed-Wing Aircraft

$$\sum(FAM_{qr}) \leq (PH \times SRT_{FA} \times CFA \times N_{FA})$$

Where CFA is the capacity of the fixed wing aircraft,

q (origin node index) and r (destination node index) are c, d, e, f. g. h, i, j, k, l, m, n, o, p.

PH is the planning horizon in days

SRT_{FA} is the average number of sorties per aircraft per day

N_{FA} is the number of available aircraft

E. DESCRIPTION OF THE SECOND MODEL

1. Decision Variables

As mentioned before, there are 281 decision variables divided into the following four types (based on modes of transportation):

- Variables that describe the number of shipments transferred by trucks (they are noted with letters TR (=trucks) followed by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $TRS_{sender-receiver}^{type-of-items}$. There are 115 decision variables of this type.

- Variables that describe the number of shipments transferred by air using fixed-wing aircraft (they are noted with the letter FA (fixed-wing aircraft), followed by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $FAS_{sender-receiver}^{type-of-items}$. There are 4 decision variables of this type.
- Variables that describe the number of shipments transferred by air using a helicopter (they are noted with letter HE (=helicopter), followed by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $HES_{sender-receiver}^{type-of-items}$. There are 137 decision variables of this type.
- Variables that describe the number of shipments transferred by sea (they are noted with letters SE (=sea), follow by indexes that show the type of items that are transferred and the locations of the sender and receiver). Those variables are denoted as $SES_{sender-receiver}^{type-of-items}$. There are 25 decision variables of this type.

The notation of the locations is the same as in the first model.

2. Objective Function

The objective function for this model seeks to minimize the total transportation cost. The objective function is expressed as the sum of the product of the number of shipments and the cost of shipment. The costs of each shipment were shown in Tables 22, 27, 32, and, 36 of Chapter V. Those tables provide the numerical coefficients of the objective function for a case where no earthquake has happened. Such case is defined as the base line of the first model. The optimal solution of that may be used for comparison with the optimal solutions of the earthquake scenarios.

As we mentioned before, for each scenario the routes that cannot be used due to damages to the infrastructure (for example, a damaged road) will be assigned a very large transportation cost (10,000 € per kilogram, so in case of a shipment that transferred by truck the cost will be 8,000 kg × 10,000 €/kg = 80,000,000 €). By doing so, we are expecting that the model will not use that route. The transportation costs (and therefore the coefficients of the objective functions) for each earthquake scenario will be shown in the next chapter.

3. Constraints

The constraints are distinguished into two categories, as it happens in the first model. The first category includes the flow balance requirement for each node and the second type includes the capacity of the available transportation means.

a. Flow Balance Constraints

The types of constraints are the same with the first model. However, this model has 60% fewer constraints. Therefore, we have:

- Demand constraints: there are 8 constraints that deal with the final destination demands. The demand calculations are following.
- Constraints from the transshipment points: there are 6 constraints since we have 6 transshipment points. For those nodes, we are assuming that the net flow will be greater than or equal to 0.
- Supply constraints: there are 2 constraints since we have 2 sources.

The mathematical notation for the constraints is:

1) Equations for the Final Destination

(i) Covering Demand on Pastra:

$$\mathrm{CHE}\times\sum_{x_p}\mathrm{HES}_{x_p p}-\mathrm{CHE}\times\sum_{x_p}\mathrm{HES}_{p x_p}+\mathrm{CTR}\times\sum_{y_p}\mathrm{TRS}_{y_p p}-\mathrm{CTR}\times\sum_{y_p}\mathrm{TRS}_{p y_p}\ \geq \mathrm{D}_p$$

Where x_p is the destination (or origin) index from (or to) Pastra by helicopters (c, d, h, g, f, o, n, m, j, k, l and i), y_p is the destination (or origin) index from (or to) Pastra by trucks (h, g, f, o, n, m, j, k, l and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(ii) Covering Demand on Omala:

$$CHE\times\sum_{x_o}\mathrm{HES}_{x_o o}-\mathrm{CHE}\times\sum_{x_o}\mathrm{HES}_{o x_o}+\mathrm{CTR}\times\sum_{y_o}\mathrm{TRS}_{y_o o}-\mathrm{CTR}\times\sum_{y_o}\mathrm{TRS}_{o y_o}\ \geq \mathrm{D}_o$$

Where x_o is the destination (or origin) index from (or to) Omala by helicopters (c, d, h, g, f, p, n, m, j, k, l and i), y_o is y_p is the destination (or origin) index

from (or to) Omala by trucks (h, g, f, p, n, m, j, k, l and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(iii) Covering Demand on Ceramii:

$$CHE\times\sum_{x_n}\mathrm{HES}_{x_n n}\text{-}\mathrm{CHE}\times\sum_{x_n}\mathrm{HES}_{n x_n}+\mathrm{CTR}\times\sum_{y_n}\mathrm{TRS}_{y_n n}\text{-}\mathrm{CTR}\times\sum_{y_n}\mathrm{TRS}_{n y_n}\geq \mathrm{D}_n$$

Where x_n is the destination (or origin) index from (or to) Ceramii by helicopters (c, d, h, g, f, p, o, m, j, k, l and i), y_n is the destination (or origin) index from (or to) Ceramii by trucks (h, g, f, p, o, m, j, k, l and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(iv) Covering Demand on Vasilikadi:

$$CHE\times\sum_{x_m}\mathrm{HES}_{x_m m}\text{-}\mathrm{CHE}\times\sum_{x_m}\mathrm{HES}_{m x_m}+\mathrm{CTR}\times\sum_{y_m}\mathrm{TRS}_{y_m m}\text{-}\mathrm{CTR}\times\sum_{y_m}\mathrm{TRS}_{m y_m}\geq \mathrm{D}_m$$

Where x_m is the destination (or origin) index from (or to) Vasilikadi by helicopters (c, d, h, g, f, p, o, n, j, k, l and i), y_m is the destination (or origin) index from (or to) Vasilikadi by trucks (h, g, f, p, o, n, j, k, l and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(v) Covering Demand on Santa Efimia:

$$CHE\times\sum_{x_j}\mathrm{HES}_{x_j j}\text{-}\mathrm{CHE}\times\sum_{x_j}\mathrm{HES}_{j x_j}+\mathrm{CTR}\times\sum_{y_j}\mathrm{TRS}_{y_j j}\text{-}\mathrm{CTR}\times\sum_{y_j}\mathrm{TRS}_{j y_j}\geq \mathrm{D}_j$$

Where x_j is the destination (or origin) index from (or to) Santa Efimia by helicopters (c, d, h, g, f, p, o, n, m, k, l and i), y_n is the destination (or origin) index from (or to) Santa Efimia by trucks (h, g, f, p, o, n, m, k, l and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(vi) Covering Demand on Sami:

$$CHE\times\sum_{x_k}\mathrm{HES}_{x_k k}\text{-}\mathrm{CHE}\times\sum_{x_k}\mathrm{HES}_{k x_k}+\mathrm{CTR}\times\sum_{y_k}\mathrm{TRS}_{y_k k}\text{-}\mathrm{CTR}\times\sum_{y_k}\mathrm{TRS}_{k y_k}+$$
$$CTR\times\sum_{z_k}\mathrm{SES}_{z_k k}\text{-}\mathrm{CTR}\times\sum_{z_k}\mathrm{SES}_{k z_k}\geq \mathrm{D}_k$$

Where x_k is the destination (or origin) index from (or to) Sami by helicopters (c, d, h, g, f, p, o, n, m, j, l and i), y_k is the destination (or origin) index from (or to) Sami by trucks (h, g, f, p, o, n, m, j, l and i), z_k is the destination (or origin) index from (or to) Sami by sea (g, f, l, and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(vii) Covering Demand on Lixouri:

$$CHE\times\sum_{x_l}\mathrm{HES}_{x_l l}\text{-CHE}\times\sum_{x_l}\mathrm{HES}_{\mathrm{l}x_l}+\mathrm{CTR}\times\sum_{y_l}\mathrm{TRS}_{y_l l}\text{-CTR}\times\sum_{y_l}\mathrm{TRS}_{\mathrm{l}y_l}+$$
$$CTR\times\sum_{z_l}\mathrm{SES}_{z_l l}\text{-CTR}\times\sum_{z_l}\mathrm{SES}_{\mathrm{l}z_l}\geq \mathrm{D}_l$$

Where x_l is the destination (or origin) index from (or to) Lixouri by helicopters (c, d, h, g, f, p, o, n, m, j, k and i), y_l is the destination (or origin) index from (or to) Lixouri by trucks (h, g, f, p, o, n, m, j, k and i), z_l is the destination (or origin) index from (or to) Lixouri by sea (g, f, k, and i), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(viii) Covering Demand on Argostoli:

$$CHE\times\sum_{x_i}\mathrm{HES}_{x_i i}\text{-CHE}\times\sum_{x_i}\mathrm{HES}_{\mathrm{i}x_i}+\mathrm{CTR}\times\sum_{y_i}\mathrm{TRS}_{y_i i}\text{-CTR}\times\sum_{y_i}\mathrm{TRS}_{\mathrm{i}y_i}+$$
$$CTR\times\sum_{z_i}\mathrm{SES}_{z_i i}\text{-CTR}\times\sum_{z_i}\mathrm{SES}_{\mathrm{i}z_i}\geq \mathrm{D}_i$$

Where x_i is the destination (or origin) index from (or to) Argostoli by helicopters (c, d, h, g, f, p, o, n, m, j, k and l), y_i is the destination (or origin) index from (or to) Argostoli by trucks (h, g, f, p, o, n, m, j, k and l), z_i is the destination (or origin) index from (or to) Argostoli by sea (g, f, k, and l), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

2) Equation for the Intermediate Destinations

(i) Transportation of Relief Items Through Poros' Port:

$$CHE \times \sum_{x_g} \mathrm{HES}_{x_g g} \text{-CHE} \times \sum_{x_g} \mathrm{HES}_{\mathrm{gx}_g} + \mathrm{CTR} \times \sum_{y_g} \mathrm{TRS}_{y_g g} \text{-CTR} \times \sum_{y_g} \mathrm{TRS}_{\mathrm{gy}_g} +$$
$$CTR \times \sum_{z_g} \mathrm{SES}_{z_g g} \text{-CTR} \times \sum_{z_g} \mathrm{SES}_{\mathrm{gz}_g} \geq 0$$

Where x_g is the destination (or origin) index from (or to) Poros by helicopters (c, d, h, i, f, p, o, n, m, j, k and l), y_g is the destination (or origin) index from (or to) Poros by trucks (h, i, f, p, o, n, m, j, k and l), z_g is the destination (or origin) index from (or to) Poros by sea (i, f, k, and l), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(ii) Transportation of Relief Items Through Port of Fiscardo:

$$CHE \times \sum_{x_f} \mathrm{HES}_{x_f f} \text{-CHE} \times \sum_{x_f} \mathrm{HES}_{\mathrm{fx}_f} + \mathrm{CTR} \times \sum_{y_f} \mathrm{TRS}_{y_f f} \text{-CTR} \times \sum_{y_f} \mathrm{TRS}_{\mathrm{fy}_f} +$$
$$CTR \times \sum_{z_f} \mathrm{SES}_{z_f f} \text{-CTR} \times \sum_{z_f} \mathrm{SES}_{\mathrm{fz}_f} \geq 0$$

Where x_f is the destination (or origin) index from (or to) Fiscardo by helicopters (c, d, h, i, g, p, o, n, m, j, k and l), y_f is the destination (or origin) index from (or to) Fiscardo by trucks (h, i, g, p, o, n, m, j, k and l), z_f is the destination (or origin) index from (or to) Fiscardo by sea (i, g, k, and l), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

(iii) Transportation of Relief Items Through Airport of Kefalonia:

$$CHE \times \sum_{x_h} \mathrm{HES}_{x_h h} \text{-CHE} \times \sum_{x_h} \mathrm{HES}_{\mathrm{hx}_h} + \mathrm{CTR} \times \sum_{y_h} \mathrm{TRS}_{y_h h} \text{-CTR} \times \sum_{y_h} \mathrm{TRS}_{\mathrm{hy}_h} +$$
$$CFA \times \sum_{u_h} \mathrm{FAS}_{u_h h} \geq 0$$

Where x_h is the destination (or origin) index from (or to) airport of Kefalonia by helicopters (c, d, f, i, g, p, o, n, m, j, k and l), y_h is the destination (or origin) index from (or to) airport of Kefalonia by trucks (f, i, g, p, o, n, m, j, k and l), u_h is the or

origin index to airport of Kefalonia by fixed wings airplane (c and d), CHE is the capacity of the helicopter, CTR is the capacity of the truck and CFA is the capacity of the fixed-wing aircraft.

(iv) Transportation of Relief Items Through Airport of Athens:

$$\mathrm{CTR}\times\mathrm{TRS}_{ac}+CHE\times\mathrm{HES}_{dc}\text{-}\mathrm{CHE}\times\sum_{\mathrm{x}_c}\mathrm{HES}_{\mathrm{cx}_c}+$$
$$CFA\times\mathrm{FAS}_{dc}\text{-}\mathrm{CFA}\times\sum_{u_c}\mathrm{FAS}_{\mathrm{cu}_c}\geq 0$$

Where x_c is the destination index from airport of Athens by helicopters (h, d, f, i, g, p, o, n, m, j, k and l), u_c is the destination index from airport of Athens by fixed wings airplane (h and d), CHE is the capacity of the helicopter, CTR is the capacity of the truck and CFA is the capacity of the fixed-wing aircraft.

(v) Transportation of Relief Items Through Airport of Araxos:

$$CHE\times\sum_{\mathrm{x}_d}\mathrm{HES}_{\mathrm{x}_d d}\text{-}\mathrm{CHE}\times\sum_{\mathrm{x'}_d}\mathrm{HES}_{\mathrm{dx}_d}+\mathrm{CTR}\times\sum_{y_d}\mathrm{TRS}_{y_d d}+$$
$$CFA\times FAS_{cd}-CFA\times\sum_{u_d}\mathrm{FAS}_{du_d}\geq 0$$

Where x_d is the origin index to airport of Araxos by helicopters (c and e), x'_d is the destination index from airport of Araxos by helicopters (c, d, f, i, g, p, o, n, m, j, k and l), y_d is the destination index from airport of Araxos by trucks (a and b), u_d is the destination index from airport of Araxos by fixed wings airplane (c and h), CHE is the capacity of the helicopter, CTR is the capacity of the truck and CFA is the capacity of the fixed-wing aircraft.

(vi) Transportation of Relief Items Through Patras' Port:

$$CHE\times\sum_{\mathrm{x}_e}\mathrm{HES}_{\mathrm{x}_e e}\text{-}\mathrm{CHE}\times\mathrm{HES}_{\mathrm{ed}}+\mathrm{CTR}\times\sum_{y_e}\mathrm{TRS}_{y_e e}\text{-}\mathrm{CTR}\times\sum_{z_e}\mathrm{SES}_{\mathrm{ez}_e}\geq 0$$ Where x_e is the origin index to Patras' port by helicopters (c and d), y_e is the origin index to Patras' port by trucks (a and b), z_e is the destination index from Patras' port by sea (g, f, k, and l), CHE is the capacity of the helicopter and CTR is the capacity of the truck.

3) Equations of the Starting Points:

(i) Getting Relief Items from Athens’ Log Center:

$$CTR \times TRS_{ac} + CTR \times TRS_{ad} + CTR \times TRS_{ae} \leq 0.6 \times \sum_{d_a} D_{d_a}$$

Where d_d is the final destination index (i, j, k, l, m, n, o, and p) and CTR is the capacity of the truck.

(ii) Getting Relief Items from Patras’ Log Center:

$$CTR \times TRS_{bd} + CTR \times TRS_{be} \leq 0.6 \times \sum_{d_b} D_{d_b}$$

Where d_d is the final destination index (i, j, k, l, m, n, o, and p) and CTR is the capacity of the truck.

The numerical coefficients of these constraints are shown in Tables 55 and 56. Those coefficients are distinguished by the transportation method that is used, and they are the same for every scenario of the model. We should note that these coefficients are not repeated for every type of item that is transferred (food, water, medicine, etc.) because in that model decision variables are the number of shipments not the masses of the items that are transferred. In those tables bidirectional arcs are noted with two numbers (the first defines the outflows of the origin node of the arc and the second defines the inflows of the origin node of the arc), while unidirectional nodes are noted with one number.

Table 55. Coefficients for sea transportation constraints of the second model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	8000	8000	8000	8000	8000
Port of Fiscardo	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Port of Poros	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000
Argostoli	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000
Sami	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000
Lixouri	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0

Table 56. Coefficients for airlifts (using fixed-wing aircraft) constraints of the second model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	19356	19356
Araxos airport	19356	0	19356

The assumptions of the population of the island and the capacity of the logistics centers are the same in both models. Therefore, the demand of each final destination is calculated by adding the masses of the three types of items (from Table 52) that are demanded in each destination. Therefore, Table 57 derives from Table 52. On the other hand, the supply of the logistics center is calculated by adding the masses of the three types of items (from Table 53) that are supplied by center. Therefore, from Table 53 it is implied that each logistics center will not supply more than 570,972 kg.

Table 57. Demands of Kefalonia municipalities (second model)

	Demand in kg
Demand on Pastra for relief items	**100,368**
Demand on Omala for relief items	**27,521**
Demand on Ceramii for relief items	**121,878**
Demand on Vasilikadi for relief items	**51,307**
Demand on Lixouri for relief items	**204,813**
Demand on Sami for relief items	**75,667**
Demand on Santa Efimia for relief items	**40,904**
Demand on Argostoli for relief items	**329,046**
Total mass to be shipped	**951,504**

Table 58. Coefficients for truck transportation constraints of the second model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	8000	8000	8000											
Patras logistic center		8000	8000											
Port of Fiscardo				0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Port of Poros				-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Airport of Kefalonia				-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Argostoli				-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Santa Efimia				-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Sami				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Lixouri				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000	-8000/8000
Vasilikadi				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000	-8000/8000
Ceramii				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000	-8000/8000
Omala				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0	-8000/8000
Pastra				-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	-8000/8000	0

Table 59. Coefficients for airlifts (using helicopters) constraints of the second model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport	**0**	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284
Araxos airport	12284	**0**	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284	12284
Patras port		12284	**0**											
Port of Fiscardo				**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Port of Poros				-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Airport of Kefalonia				-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Argostoli				-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Santa Efimia				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Sami				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Lixouri				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284
Vasilikadi				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284	-12284/ 12284
Ceramii				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284	-12284/ 12284
Omala				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**	-12284/ 12284
Pastra				-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	-12284/ 12284	**0**

b. Transportation Means Capacity Constraints

The second model (as the first) is not an ordinary transshipment model because the transportation of the relief commodities must be completed within specific time limits (3 days from the time that the earthquake happened). Therefore, we need a fourth type of constraint that will incorporate the restriction of time. In that type of constraint, we will take the same consideration as in the first model:

- The number of each type of vehicle (trucks, fixed-wing airplanes, helicopters and boats) that we can use (available vehicles)
- The maximum load capacity (in kilograms) that each type of vehicle can transfer
- The cruise (or the economy) speed (kilometers per hour) that ships and trucks move
- The maximum number of hours per day that each type of vehicle can be used. For example, aircraft and helicopters should be inspected at least at the beginning and the end of each day. Additionally, helicopters can land during night only in airports or in helipads.
- The average number of sorties that an aircraft (helicopter or fixed-wing airplane) may perform per day of operations and the average duration of each sortie. The average duration of each sortie includes the required time to load and unload the aircraft.

The above assumptions will provide us with the capacity of each type of vehicle for the period of the available 3 days after the earthquake. The capacity restrictions of each type of truck and ship should be less than or equal to the sum of the product of the shipment (in kilograms) that will be transferred through each route and the distance of each route. The capacity restrictions for the airlifts should be less than or equal to the masses (in kg) of items that can be transported given the above assumptions.

Now we will discuss each constraint:

a. Capacity of trucks in the mainland (Athens–Patras routes). We are expecting that 10 (8-ton) trucks will be used for item transportation, out of the 850 that the Armed Forces have in their inventory, for an earthquake relief operation. We assume that each truck will be available for 12 hours per day (we assume that a truck is not going

to be available 24 hours per day because time is required for driver rest, to load and unload the truck, etc.). As mentioned in Chapter V, the average speed of such trucks is 60 km per hour. Therefore, the capacity of the trucks that may be used will be 172,800,000 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route times the capacity of the trucks (since the decision variables are number of shipments). Those coefficients are shown in the following table.

Table 60. Coefficients of the trucks restriction capacity for mainland destinations of the second model

From/To	Athens airport	Araxos airport	Patras port
Athens logistic center	40,000	1,840,000	1,600,000
Patras logistic center	N/A	40,000	40,000

b. We are expecting that 10 (8-ton) trucks will be used for item transportation on the island, out of the 850 that the Armed Forces have in their inventory, for an earthquake relief operation. We assume that each truck will be available for 12 hours per day (we assume that a truck is not going to be available 24 hours per day because time is required for driver rest, to load and unload the truck, etc.). As mentioned in Chapter V, the average speed of such trucks is 35 km per hour. Therefore, the capacity of the trucks that may be used will be 100,800,000 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route. Those coefficients are implied from the Table 15 of Chapter IV by multiplying those distances by the truck capacity (8,000 kg). The following table shows those coefficients.

Table 61. Decision variables coefficients for trucks capacity restriction (second model)

	Argostoli	Vasilikadi	Pastra	Ceramii	Sami	Santa Efimia	Lixouri	Omala	Poros	Fiscardo	Airport
Argostoli	0	344000	232000	96000	216000	264000	280000	144000	304000	424000	96000
Vasilikadi	344000	0	464000	424000	240000	176000	336000	344000	440000	80000	416000
Pastra	232000	464000	0	208000	232000	296000	496000	200000	72000	512000	248000
Ceramii	96000	424000	208000	0	248000	304000	336000	192000	280000	488000	56000
Sami	216000	240000	232000	248000	0	64000	264000	104000	200000	304000	264000
Santa Efimia	264000	176000	296000	304000	64000	0	320000	160000	264000	240000	328000
Lixouri	280000	336000	496000	336000	352000	280000	0	360000	520000	408000	384000
Omala	144000	344000	200000	192000	104000	160000	360000	0	160000	480000	200000
Poros	144000	440000	72000	280000	200000	264000	520000	160000	0	504000	296000
Fiscardo	424000	80000	512000	488000	304000	240000	408000	480000	504000	0	480000
Airport	80000	416000	248000	56000	264000	328000	384000	200000	296000	480000	0

c. We are expecting that 2 ships, of the 5 that are operating in the Ionian Islands, will be used for an earthquake relief operation. Each ship may transport 1,362,133 kg. We assume that each ship will be available for 12 hours per day (we assume that a ship is not going to be available 24 hours per day because time is required to load and unload, etc.). As mentioned in Chapter V, the average speed of such ships is 35 km per hour. Therefore, the capacity of the ships that may be used will be 3,466,509,466 km-kg. The coefficient of the decision variables of that constraint will be the distances in km for each route times the capacity of the trucks (since the decision variables are number of shipments). Those coefficients are shown in the following table.

Table 62. Coefficients of the ships capacity restriction (second model)

	Sami	Poros	Argostoli	Fiscardo	Lixouri	Patras
Sami	0	200000	680000	200000	656000	800000
Poros	200000	0	480000	400000	464000	696000
Argostoli	680000	480000	0	592000	40000	1096000
Fiscardo	200000	400000	592000	0	576000	944000
Lixouri	656000	464000	40000	576000	0	1056000

d. We are expecting that 2 C-130 aircraft, of the 15 that the Hellenic Air Force has in its inventory, will be used for an earthquake relief operation. Each aircraft may transport 19,356 kg (load capacity). We assume that each aircraft will be available for 12 hours per day (we assume that an aircraft is not going to be available 24 hours per day because time is required for the crew to rest and for maintenance activities). Within those 12 hours, an airplane can perform 8 sorties of 1.5 hours per sortie. Therefore, the capacity restriction of the aircraft will be defined as the mass of items that may be transferred and is calculated as the product of the load capacity of the aircraft per sortie and the number of sorties for the three days of operations. So the restriction capacity of the aircraft will be 929,088 kg. The coefficient of the decision variables for those restrictions will be the load capacity of the aircraft.

e. We are expecting that 4 CH-47 helicopters, of the 17 that the Hellenic Army has in its inventory, will be used for an earthquake relief operation. Each helicopter may transport 12,284 kg (load capacity). We assume that each aircraft will be available for 12 hours per day (we assume that an aircraft is not going to be available 24 hours per day because time is required for the crew to rest and for maintenance activities). Within those 12 hours, an airplane can perform 8 sorties of 1.5 hours per sortie. Therefore, the capacity restriction of the aircraft will be defined as the mass of items that may be transferred and is calculated as the product of the load capacity of the aircraft per sortie and the number of sorties for the three days of operations. So the restriction capacity of the aircraft will be 1,179,264 kg. The coefficient of the decision variables for those restrictions will be the load capacity of the helicopter.

The mathematical notation for these constraints is:

1) Quantities of Relief Items Transported Using Trucks for Routes on the Island:

$$\sum (TRS_{qr} \times CTR \times RL_{qr}) \leq (PH \times Hr_{TR}^{Isl} \times S_{TR}^{Isl} \times N_{TR}^{Isl} \times CTR)$$

Where CTR is the capacity of the truck,

q (origin node index) and r (destination node index) are f, g, h, I, j, k, l, m, n, o, p

RL_{qr} is the length of the land route in km from origin node q to destination node r

PH is the planning horizon in days

S_{TR}^{Isl} is the average speed for the trucks on the island routes

N_{TR}^{Isl} is the number of trucks doing the transportations on the island

2) Quantities of Relief Items Transported Using Trucks for Routes off the Island:

$$\sum (TRS_{qr} \times CTR \times RL_{qr}) \leq (PH \times Hr_{TR}^{Mnl} \times S_{TR}^{Mnl} \times N_{TR}^{Mnl} \times CTR)$$

Where CTR is the capacity of the truck,

q (origin node index) and r (destination node index) are c, d, e

RL_{qr} is the length of the land route in km from origin node q to destination node r

PH is the planning horizon in days

S_{TR}^{Mnl} is the average speed for the trucks on mainland routes

N_{TR}^{Mnl} is the number of trucks doing the transportations off the island

3) Quantities of Relief Items Transported Using Ships:

$$\sum (SES_{qr} \times CTR \times SEL_{qr}) \leq (PH \times Hr_{SE} \times S_{SE} \times N_{SE} \times CTR)$$

Where CTR is the capacity of each truck loaded on the ships,

q (origin node index) and r (destination node index) are f, g, I, k, l

SEL_{qr} is the length of the sea route in km from origin node q to destination node r

PH is the planning horizon in days

S_{SE} is the average speed for the ships

N_{SE} is the number of ships doing the transportations

4) Quantities of Relief Items Transported Using Helicopters

$$\sum(HES_{qr} \times CHE) \leq (PH \times SRT_{HE} \times CHE \times N_{HE})$$

Where CHE is the capacity of the helicopter,

q (origin node index) and r (destination node index) are c, d, e, f. g. h, i, j, k, l, m, n, o, p

PH is the planning horizon in days

SRT_{HE} is the average number of sorties per helicopter per day

N_{HE} is the number of available helicopters

5) Quantities of Relief Items Transported Using Fixed-Wing Aircraft

$$\sum(FAS_{qr} \times CFA) \leq (PH \times SRT_{FA} \times CFA \times N_{FA})$$

Where CFA is the capacity of the fixed wing aircraft,

q (origin node index) and r (destination node index) are c, d, e, f. g. h, i, j, k, l, m, n, o, p

PH is the planning horizon in days

SRT_{HE} is the average number of sorties per aircraft per day

N_{HE} is the number of available aircraft

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VIII. THE EARTHQUAKE SCENARIOS

A. INTRODUCTION

Earthquakes are natural phenomena that cannot be accurately predicted. Therefore, in order to test a mathematical model that could be used for planning and optimizing logistics for earthquake relief operations, it is necessary to create earthquake scenarios. Those scenarios should be based on the conclusions of special scientists (like professor Papazachos), who observe earthquakes and record their consequences, in order to be realistic. Additionally, such scenarios should consider the following questions:

- Where may the earthquake's epicenter be?
- What may the earthquake's intensity (or magnitude) be?
- What are the expected damages from such an earthquake?
- What are the expected human casualties and losses from such an earthquake?

The answers to these questions will provide the necessary inputs of our model for the transportation means and the routes that may be used, which affect the total transportation cost. In this chapter, we shall discuss how the answers relate to our model inputs, and we will describe the three scenarios that we have used to test our model.

Figure 17. Landslide in Pefkoulia on Lefkada Island (next to Kefalonia in the Ionian Sea), after the 2003 M 6.4 earthquake (From: Papadopoulos, Karastathis, Ganas, Pavlides, Fokaefs, & Orfanogiannaki, 2003)

B. CREATING EARTHQUAKE SCENARIOS

As mentioned in Chapter II, the earthquake is characterized by its epicenter, its magnitude, and its consequences in the human societies. That is the reason why the answers of the above questions are important. Following, we shall discuss ways to answer those questions.

1. Earthquake Epicenter

We may not be able to predict where and when an earthquake shall happen but we may use statistical data to make plausible assumptions where it may happen. We may use either a probabilistic model or a deterministic in order to infer such information. Usage of a probabilistic model is beyond the scope of this project and therefore a deterministic one will be used.

In Chapter IV, we presented the nineteen major earthquakes that have happened in Kefalonia since the 15th century BC. From the analysis of the data of these earthquakes we concluded that the earthquakes' epicenters are located usually near the west and southwest part of the island. So it seems that an earthquake in that region is very probable, and therefore we choose an epicenter at 38.10^o North and 20.40^o East. However, we noticed that two catastrophic earthquakes happened in the east (at 12 Aug 1953 at 38.30^o North and 20.80^o East) and the north (in 4 Feb 1867 at 38.39^o North and 20.52^o East) part of the island. Therefore, we decided that those two would be the epicenters for the second and the third scenario, respectively.

2. Earthquake Magnitude

As Professor Papazachos stated (and was presented in Chapter III) the Ionian tectonic fault (where the European plate meets the Aegean plate) may produce an earthquake of 7.4 (Richter scale) once every 70 years. Therefore, an earthquake of such magnitude is expected to take place, and we decided to use that information.

3. Expected Damages

The damages in the infrastructure are related to the macro seismic intensity, as discussed in Chapter II. On the other hand, the macro seismic intensity of an earthquake in a specific place is calculated as a function of the distance from the epicenter and the magnitude of the earthquake. The mathematical formula of that is shown as equation 8 of Chapter II. Using that formula can provide us with the necessary information to infer the transportation means and the routes that may be used in each earthquake scenario.

If from the above formula a town is expected to suffer catastrophic damages, then it will be assumed that it will not be feasible to reach that town by ground or by sea. Such a case, that a town is isolated from sea and ground, will be noted in our models by assigning a very high transportation cost in the objective function for the route to and from that town.

4. Human Losses and Casualties

Knowledge of the human losses and casualties, in conjunction with the population of the place that is hit by an earthquake, is used to calculate the demand in relief commodities. Professor Papazachos (as mentioned in Table 6 of Chapter III) has provided a method to estimate human losses and casualties from an earthquake. In our case the population of Kefalonia (even in the summer time) is not expected to get over 45,000 people. Therefore, we assume that the demand in relief commodities will not change substantially if we do not consider human casualties and losses.

C. DESCRIPTION OF THE EARTHQUAKE SCENARIOS

1. Earthquake Scenario 1

The epicenter of scenario 1 is at 38.10^{o} North and 20.40^{o} East and the earthquake magnitude will be 7.4 on the Richter scale. Therefore, by using equation 8 of Chapter II for each node in the island we will have the results that are shown on Table 63.

Table 63. Micro seismic intensity in the nodes in the island for scenario 1

Place	Distance from epicenter (In Km)	MMI	Damages
Fiscardo	42.61	VII	Negligible
Argostoli	10.65	VIII	**Considerable**
Omala	18.76	VIII	**Considerable**
Poros	31.76	VII	Negligible
Sami	26.18	VII	Negligible
S. Efimia	27.74	VII	Negligible
Lixouri	11.76	VIII	**Considerable**
Airport of Kefalonia	7.99	IX	**Considerable**
Ceramii	12.53	VIII	**Considerable**
Vasilikadi	37.41	VII	Negligible
Pastra	29.81	VII	Negligible

Argostoli, Omala, Lixouri, Airport of Kefalonia, Ceramii depict the places on the island where there appears to be considerable infrastructure damages, such as partial building collapse, rocks, fall of chimneys, buildings shifted off foundations, etc. Specifically, from Table 63 it is inferred that:

- Roads from and to Argostoli, Omala, Lixouri, Airport of Kefalonia and Ceramii cannot be used
- The ports of Lixouri and Argostoli cannot be used
- Fixed-wing airplanes cannot land at the airport of Kefalonia

The transportation costs for those nodes will be assumed to be quite high, while the transportation costs of the routes that have not been affected by the earthquake are taken from Chapter V. In conclusion:

- Tables 64, 65 and 68 show the costs used in the first model
- Tables 66, 67 and 69 show the costs used in the second model

Table 64. Costs for sea transportations of scenario 1 in the first model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0.04191403	0.03090272	10000	0.03552037	10000
Port of Fiscardo	0	0.00476129	10000	0.00238065	10000
Port of Poros	0.00476129	0	10000	0.00238065	10000
Argostoli	10000	10000	0	10000	10000
Sami	0.00238065	0.00238065	10000	0	10000
Lixouri	10000	10000	10000	10000	0

Table 65. Costs for airlifts using fixed-wing aircraft of scenario 1 in the first model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	10000	10000
Araxos airport	10000	0	10000

Table 66. Costs for sea transportations of scenario 1 in the second model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	335.3122	247.2218	80000000	284.163	80000000
Port of Fiscardo	0	38.09032	80000000	19.0452	80000000
Port of Poros	38.09032	0	80000000	19.0452	80000000
Argostoli	80000000	80000000	0	80000000	80000000
Sami	19.0452	19.0452	80000000	0	80000000
Lixouri	80000000	80000000	80000000	80000000	0

Table 67. Costs for airlifts using fixed wing aircrafts of scenario 1 in the second model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	193560000	193560000
Araxos airport	193560000	0	193560000

Table 68. Costs for transportation using trucks of scenario 1 in the first model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0.0001**	0.0126	0.0112											
Patras Logistic center		**0.0001**	**0.0001**											
Port of Fiscardo				**0**	0.0048	10000	10000	0.0030	0.0034	10000	0.0021	10000	10000	0.0048
Port of Poros				0.0048	**0**	10000	10000	0.0032	0.0028	10000	0.0044	10000	10000	0.0021
Airport of Kefalonia				10000	10000	0	10000	10000	10000	10000	10000	10000	10000	10000
Argostoli				10000	10000	10000	0	10000	10000	10000	10000	10000	10000	10000
Santa Efimia				0.0030	0.0032	10000	10000	**0**	0.0020	10000	0.0027	10000	10000	0.0033
Sami				0.0034	0.0028	10000	10000	0.0020	**0**	10000	0.0030	10000	10000	0.0030
Lixouri				10000	10000	10000	10000	10000	10000	0	10000	10000	10000	10000
Vasilikadi				0.0021	0.0044	10000	10000	0.0027	0.0030	10000	**0**	10000	10000	0.0045
Ceramii				10000	10000	10000	10000	10000	10000	10000	10000	0	10000	10000
Omala				10000	10000	10000	10000	10000	10000	10000	10000	10000	0	10000
Pastra				0.0048	0.0021	10000	10000	0.0033	0.0030	10000	0.0045	10000	10000	**0**

Table 69. Costs for transportations using trucks of scenario 1 in the second model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	8	100.8	89.6	0	0	0	0	0	0	0	0	0	0	0
Patras logistic center	0	8	8	8	0	0	0	0	0	0	0	0	0	0
Port of Fiscardo	0	0	0	0	38.4	80000000	80000000	24	27.2	80000000	16.8	80000000	80000000	38.4
Port of Poros	0	0	0	38.4	0	80000000	80000000	25.6	22.4	80000000	35.2	80000000	80000000	16.8
Airport of Kefalonia	0	0	0	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Argostoli	0	0	0	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Santa Efimia	0	0	0	24	25.6	80000000	80000000	0	16	80000000	21.6	80000000	80000000	26.4
Sami	0	0	0	27.2	22.4	80000000	80000000	16	0	80000000	24	80000000	80000000	24
Lixouri	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000
Vasilikadi	0	0	0	16.8	35.2	80000000	80000000	21.6	24	80000000	0	80000000	80000000	36
Ceramii	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000
Omala	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000
Pastra	0	0	0	38.4	16.8	80000000	80000000	26.4	24	80000000	36	80000000	80000000	0

2. Earthquake Scenario 2

The epicenter of scenario 2 is at 38.30^o North and 20.80^o East and the earthquake magnitude will be 7.4 on the Richter scale. Therefore, by using equation 8 of Chapter II for each node in the island, we will have the results that are shown in Table 70.

Table 70. Micro seismic intensity in the nodes in the island for scenario 2

Place	Distance from epicenter (In Km)	MMI	Damages
Fiscardo	26.35	VII	Negligible
Argostoli	30.95	VII	Negligible
Omala	21.64	VIII	**Considerable**
Poros	16.64	VIII	**Considerable**
Sami	14.37	VIII	**Considerable**
S. Efimia	17.87	VIII	**Considerable**
Lixouri	33.21	VII	Negligible
Airport of Kefalonia	32.68	VII	Negligible
Ceramii	29.23	VII	Negligible
Vasilikadi	23.94	VIII	**Considerable**
Pastra	23.06	VIII	**Considerable**

Omala, Poros, Sami, S. Efimia, Vasilikadi, and Pastra depict the places on the island where there appears to be considerable infrastructure damages, such as partial collapse of buildings, rocks, fall of chimneys, buildings shifted off foundations, etc. Specifically, from Table 70 it is inferred that:

- Roads from and to Omala, Poros, Sami, Santa Efimia, Vasilikadi and Pastra cannot be used
- The ports of Poros and Sami cannot be used
- The port of Fiscardo may be used but trucks cannot be used to transfer relief items from there, because roads from and to Vasilikadi are damaged

The transportation costs for those nodes will be assumed to be quite high, while the transportation costs of the routes that have not been affected by the earthquake are taken from Chapter V. In conclusion:

- Tables 71, 72 and 75 show the costs used in the first model
- Tables 73, 74 and 76 show the costs used in the second model

Table 71. Costs for sea transportations of scenario 2 in the first model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0.04191403	10000	0.0486629	10000	0.04688688
Port of Fiscardo	**0**	10000	0.0070467 1	10000	0.00685626
Port of Poros	10000	**0**	10000	10000	10000
Argostoli	0.00704671	10000	**0**	10000	0.00047613
Sami	10000	10000	10000	**0**	10000
Lixouri	0.00685626	10000	0.0004761 3	10000	**0**

Table 72. Costs for airlifts using fixed-wing aircraft of scenario 2 in the first model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	**0**	0.15806429	0.24957519
Araxos airport	0.15806429	**0**	0.06239380

Table 73. Costs for sea transportations of scenario 2 in the second model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	335.3122	80000000	389.3032	80000000	375.095
Port of Fiscardo	0	80000000	56.37368	80000000	54.85008
Port of Poros	80000000	0	80000000	80000000	80000000
Argostoli	56.37368	80000000	0	80000000	3.80904
Sami	80000000	80000000	80000000	0	80000000
Lixouri	54.85008	80000000	3.80904	80000000	0

Table 74. Costs for airlifts using fixed-wing aircraft of scenario 2 in the second model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	3059.492	4830.777
Araxos airport	3059.492	0	1207.694

Table 75. Costs for transportations using trucks of scenario 2 in the first model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0.0001**	0.0126	0.0112											
Patras logistic center		**0.0001**	**0.0001**											
Port of Fiscardo				0	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Port of Poros				10000	0	10000	10000	10000	10000	10000	10000	10000	10000	10000
Airport of Kefalonia				10000	10000	**0**	0.0021	10000	10000	0.0038	10000	0.0020	10000	10000
Argostoli				10000	10000	0.0021	**0**	10000	10000	0.0032	10000	0.0022	10000	10000
Santa Efimia				10000	10000	10000	10000	0	10000	10000	10000	10000	10000	10000
Sami				10000	10000	10000	10000	10000	0	10000	10000	10000	10000	10000
Lixouri				10000	10000	0.0038	0.0032	10000	10000	**0**	10000	0.0036	10000	10000
Vasilikadi				10000	10000	10000	10000	10000	10000	10000	0	10000	10000	10000
Ceramii				10000	10000	0.0020	0.0022	10000	10000	0.0036	10000	**0**	10000	10000
Omala				10000	10000	10000	10000	10000	10000	10000	10000	10000	0	10000
Pastra				10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	0

Table 76. Costs for transportations using trucks of scenario 2 in the second model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	8	100.8	89.6	0	0	0	0	0	0	0	0	0	0	0
Patras logistic center	0	8	8	0	0	0	0	0	0	0	0	0	0	0
Port of Fiscardo	0	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Port of Poros	0	0	0	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Airport of Kefalonia	0	0	0	80000000	80000000	0	16.8	80000000	80000000	30.4	80000000	16	80000000	80000000
Argostoli	0	0	0	80000000	80000000	16.8	0	80000000	80000000	25.6	80000000	17.6	80000000	80000000
Santa Efimia	0	0	0	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000
Sami	0	0	0	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000
Lixouri	0	0	0	80000000	80000000	30.4	25.6	80000000	80000000	0	80000000	28.8	80000000	80000000
Vasilikadi	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000
Ceramii	0	0	0	80000000	80000000	16	17.6	80000000	80000000	28.8	80000000	0	80000000	80000000
Omala	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000
Pastra	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0

3. Earthquake Scenario 3

The epicenter of scenario 3 is at 38.39^{o} North and 20.52^{o} East and the earthquake magnitude will be 7.4 on the Richter scale. Therefore, by using equation 8 of Chapter II for each node in the island we will have the results that are shown on Table 77.

Table 77. Micro seismic intensity in the nodes in the island for scenario 3

Place	Distance from epicenter (In Km)	MMI	Damages
Fiscardo	9.07	IX	Considerable
Argostoli	23.93	VIII	Considerable
Omala	24.26	VIII	Considerable
Poros	34.21	VII	Negligible
Sami	19.01	VIII	Considerable
S. Efimia	12.7	VIII	Considerable
Lixouri	22.13	VIII	Considerable
Airport of Kefalonia	30.6	VII	Negligible
Ceramii	30.3	VII	Negligible
Vasilikadi	4.51	IX	Considerable
Pastra	38.13	VII	Negligible

Fiscardo, Argostoli, Omala, Sami, S. Efimia, Lixouri, and Vasilikadi depict the places on the island where there appears to be considerable infrastructure damages, such as partial collapse on buildings, rocks, fall of chimneys, buildings shifted off foundations etc. Specifically, from Table 60 it is inferred that:

- Roads from and to Fiscardo, Argostoli, Omala, Sami, Santa Efimia, Lixouri and Vasilikadi can’t be used; and
- The ports of Fiscardo, Sami, Argostoli, and Lixouri cannot be used.

The transportation costs for those nodes will be assumed to be quite high, while the transportation costs of the routes that have not been affected by the earthquake are taken from Chapter V. In conclusion:

- Tables 78, 79 and 82 show the costs used in the first model
- Tables 80, 81 and 83 show the costs used in the second model

Table 78. Costs for sea transportations of scenario 2 in the first model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	10000	0.03090272	10000	10000	10000
Port of Fiscardo	**0**	10000	10000	10000	10000
Port of Poros	10000	**0**	10000	10000	10000
Argostoli	10000	10000	**0**	10000	10000
Sami	10000	10000	10000	**0**	10000
Lixouri	10000	10000	10000	10000	**0**

Table 79. Costs for airlifts using fixed-wing aircraft of scenario 2 in the first model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	**0**	0.15806429	0.24957519
Araxos airport	0.15806429	**0**	0.06239380

Table 80. Costs for sea transportations of scenario 2 in the second model

From/To	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	80000000	247.2218	80000000	80000000	80000000
Port of Fiscardo	0	80000000	80000000	80000000	80000000
Port of Poros	80000000	0	80000000	80000000	80000000
Argostoli	80000000	80000000	0	80000000	80000000
Sami	80000000	80000000	80000000	0	80000000
Lixouri	80000000	80000000	80000000	80000000	0

Table 81. Costs for airlifts using fixed-wing aircraft of scenario 2 in the second model

From/To	Athens airport	Araxos airport	Airport of Kefalonia
Athens airport	0	3059.492	4830.777
Araxos airport	3059.492	0	1207.694

Table 82. Costs for transportations using trucks of scenario 2 in the first model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0.0001**	0.0126	0.0112											
Patras logistic center		**0.0001**	**0.0001**											
Port of Fiscardo				**0**	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Port of Poros				10000	**0**	0.0033	10000	10000	10000	10000	10000	0.0032	10000	0.0021
Airport of Kefalonia				10000	0.0033	**0**	10000	10000	10000	10000	10000	0.0020	10000	0.0031
Argostoli				10000	10000	10000	**0**	10000	10000	10000	10000	10000	10000	10000
Santa Efimia				10000	10000	10000	10000	**0**	10000	10000	10000	10000	10000	10000
Sami				10000	10000	10000	10000	10000	**0**	10000	10000	10000	10000	10000
Lixouri				10000	10000	10000	10000	10000	10000	**0**	10000	10000	10000	10000
Vasilikadi				10000	10000	10000	10000	10000	10000	10000	**0**	10000	10000	10000
Ceramii				10000	0.0032	0.0020	10000	10000	10000	10000	10000	**0**	10000	0.0028
Omala				10000	10000	10000	10000	10000	10000	10000	10000	10000	**0**	10000
Pastra				10000	0.0021	0.0031	10000	10000	10000	10000	10000	0.0028	10000	**0**

Table 83. Costs for transportations using trucks of scenario 2 in the second model

From/To	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	8	100.8	89.6	0	0	0	0	0	0	0	0	0	0	0
Patras logistic center	0	8	8	0	0	0	0	0	0	0	0	0	0	0
Port of Fiscardo	0	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Port of Poros	0	0	0	80000000	0	26.4	80000000	80000000	80000000	80000000	80000000	25.6	80000000	16.8
Airport of Kefalonia	0	0	0	80000000	26.4	0	80000000	80000000	80000000	80000000	80000000	16	80000000	24.8
Argostoli	0	0	0	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000
Santa Efimia	0	0	0	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000	80000000
Sami	0	0	0	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000	80000000
Lixouri	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000	80000000
Vasilikadi	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000	80000000	80000000
Ceramii	0	0	0	80000000	25.6	16	80000000	80000000	80000000	80000000	80000000	0	80000000	22.4
Omala	0	0	0	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	80000000	0	80000000
Pastra	0	0	0	80000000	16.8	24.8	80000000	80000000	80000000	80000000	80000000	22.4	80000000	0

IX. THE RESULTS FROM THE MODELS

A. INTRODUCTION

We solved the models using Microsoft Excel 2007 and Risk Solver Platform Trial Version 9.6.3.0 Frontline Systems, INC. For the first model (from now on we shall call it continuous) Solver provided us with Answer, Structure, and Sensitivity Analysis Reports for each of the four scenarios. For the second model (from now on we shall call them integer) Solver provided us with Answer, and Solution Reports for each of the four scenarios.

Due to the magnitude of the models the reports that were produced by solver couldn't be inserted in our text "as is." Therefore, we decided to provide the information of those reports in the following, more accessible manners for the reader:

- Tables that include transportation costs for each route of the optimum solution for each scenario
- Transportation Network diagrams that show the routes that will be used and the quantities of relief items of the optimum solution for each scenario
- Maps of the island that show the routes that will be used and the quantities of relief items of the optimum solution for each scenario

In this chapter, we will present and describe the solutions; we shall also make some observations regarding those results. In the next and final chapter we offer conclusions and suggest further research.

The legend for interpreting the information presented in the tables for all scenarios is described in Table 84.

Table 84. Legend for all result tables

	Non-existent routes
	Non-feasible routes for this scenario
	Non-valid routes (origin and destination are the same)

B. BASELINE MODEL CONTINUOUS VARIABLES

1. Numerical Results

a. Truck Transportation

Table 85. Continuous variables baseline model results for food and water transported quantities using trucks, in kg

	Athens airport	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikadi**	**Ceramii**	**Omala**	**Pastra**
Athens logistic center	0	0	**75,060**											
Patras logistic center		0	**112,590**											
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	**105,285**	**8,067**	0	0	**10,118**	**24,036**	**5,427**	**19,794**
Airport of Kefalonia				0	0	0	0	0	0	0	0	0	0	0
Argostoli				0	0	0	0	0	0	0	0	0	0	0
Santa Efimia				0	0	0	0	0	0	0	0	0	0	0
Sami				0	0	0	0	0	0	0	0	0	0	0
Lixouri				0	0	0	0	0	0	0	0	0	0	0
Vasilikadi				0	0	0	0	0	0	0	0	0	0	0
Ceramii				0	0	0	0	0	0	0	0	0	0	0
Omala				0	0	0	0	0	0	0	0	0	0	0
Pastra				0	0	0	0	0	0	0	0	0	0	0

Table 86. Continuous variables baseline model results for non-perishable items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**303,908**											
Patras logistic center		0	**455,863**											
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	**426,282**	**32,662**	0	0	**40,969**	**97,319**	**21,976**	**80,143**
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 87. Continuous variables baseline model results for medical items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**1,633**											
Patras logistic center		0	**2,450**											
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	**2,292**	**175**	0	0	**220**	**523**	**118**	**431**
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

b. Ship Transportation

Table 88. Continuous variables baseline model results for food and water transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**187,650**	0	0	0
Port of Fiscardo		0	0	0	0
Port of Poros	0		0	**14,923**	0
Argostoli	0	0		0	**40,392**
Sami	0	0	0		0
Lixouri	0	0	0	0	

Table 89. Continuous variables baseline model results for non-perishable items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**759,771**	0	0	0
Port of Fiscardo		0	0	0	0
Port of Poros	0		0	**60,420**	0
Argostoli	0	0		0	**163,542**
Sami	0	0	0		0
Lixouri	0	0	0	0	

Table 90. Continuous variables baseline model results for medical items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**4,083**	0	0	0
Port of Fiscardo		0	0	0	0
Port of Poros	0		0	**324**	0
Argostoli	0	0		0	**879**
Sami	0	0	0		0
Lixouri	0	0	0	0	

c. *Fixed-Wing Aircraft Transportation*

No fixed-wing aircraft transportation was required in the optimal solution of the continuous variables baseline model.

d. *Helicopter Transportation*

No helicopter transportation was required in the optimal solution of the continuous variables baseline model.

2. Graphical Illustration of Results

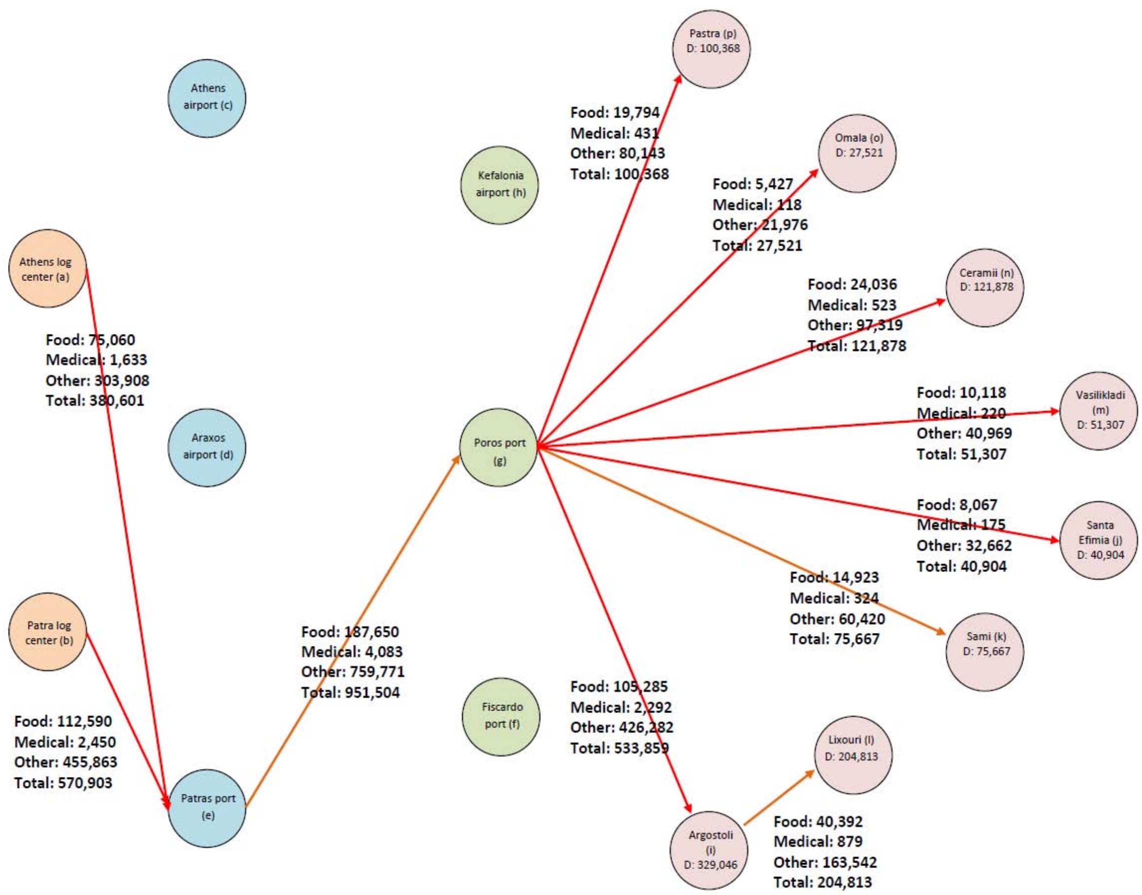

Figure 18. Graphical representation of the optimal solution of the base line model with continuous variables (legend the same as the one for Figure 16)

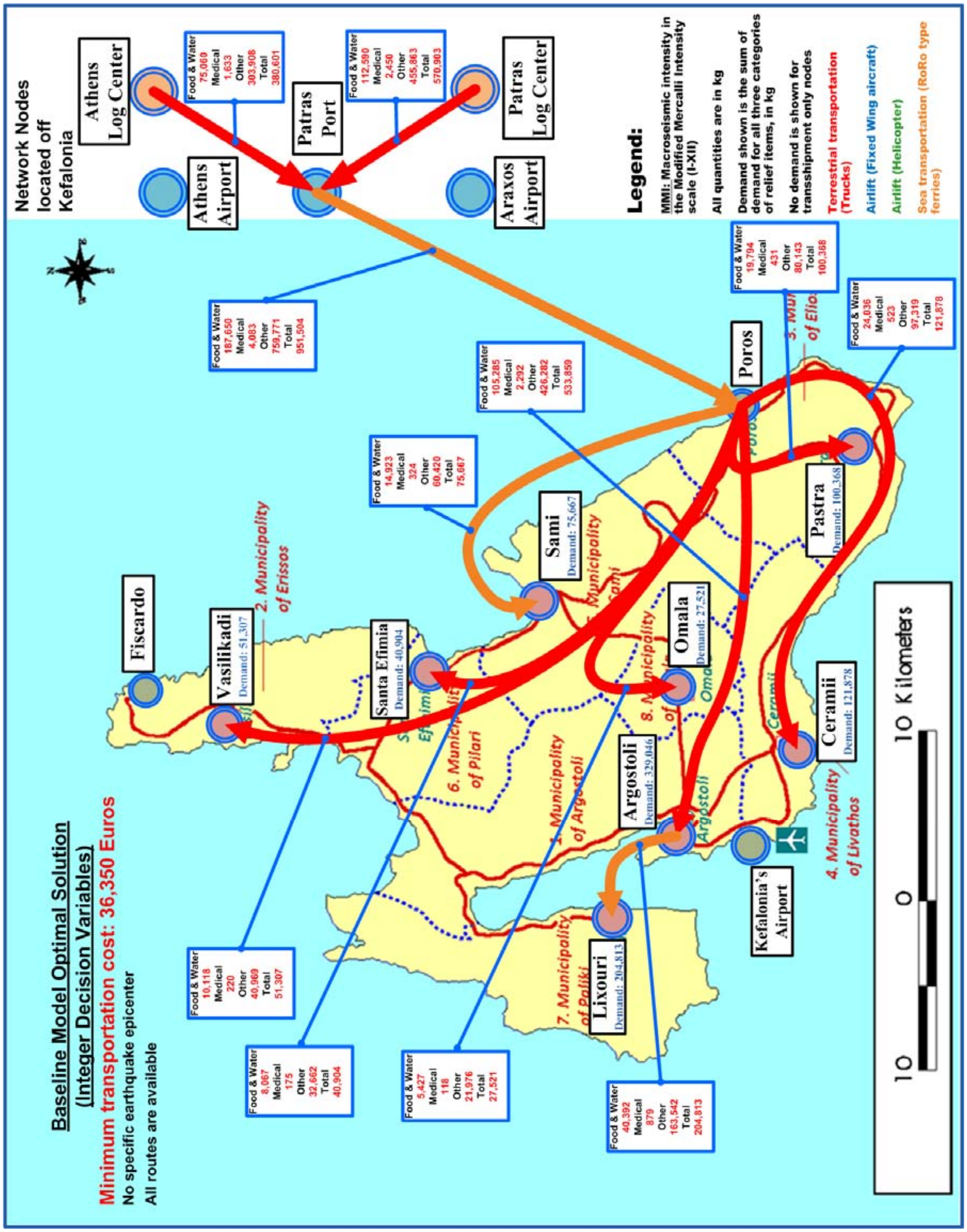

Figure 19. Continuous variables baseline model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

C. SCENARIO 1 CONTINUOUS VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 91. Scenario 1 continuous variables model results for food and water transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0**	**0**	**75,060**											
Patras logistic center		**0**	**112,590**											
Port of Fiscardo					**0**			**0**	**0**		**0**			**0**
Port of Poros				**0**				**48,459**	**0**		**10,118**			**19,794**
Airport of Kefalonia														
Argostoli														
Santa Efimia				**0**	**0**						**0**			**0**
Sami				**0**	**0**			**0**			**0**			**0**
Lixouri														
Vasilikadi				**0**	**0**			**0**	**0**					**0**
Ceramii														
Omala														
Pastra				**0**	**0**			**0**	**0**		**0**			

Table 92. Scenario 1 continuous variables model results for non-perishable items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0**	**0**	**303,908**											
Patras logistic center		**0**	**455,863**											
Port of Fiscardo					**0**			**0**	**0**		**0**			**0**
Port of Poros				**0**				**196,204**	**0**		**40,969**			**80,143**
Airport of Kefalonia														
Argostoli														
Santa Efimia				**0**	**0**						**0**			**0**
Sami				**0**	**0**			**0**			**0**			**0**
Lixouri														
Vasilikadi				**0**	**0**			**0**	**0**					**0**
Ceramii														
Omala														
Pastra				**0**	**0**			**0**	**0**		**0**			

Table 93. Scenario 1 continuous variables model results for medical items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	**0**	**0**	**1,633**											
Patras logistic center		**0**	**2,450**											
Port of Fiscardo					**0**			**0**	**0**		**0**			**0**
Port of Poros				**0**				**1,054**	**0**		**220**			**431**
Airport of Kefalonia														
Argostoli														
Santa Efimia				**0**	**0**						**0**			**0**
Sami				**0**	**0**			**0**			**0**			**0**
Lixouri														
Vasilikadi				**0**	**0**			**0**	**0**					**0**
Ceramii														
Omala														
Pastra				**0**	**0**			**0**	**0**		**0**			

b. Ship Transportation

Table 94. Scenario 1 continuous variables model results for food and water transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**187,650**		0	
Port of Fiscardo		0		0	
Port of Poros	0			**109,279**	
Argostoli					
Sami	0	0			
Lixouri					

Table 95. Scenario 1 continuous variables results for non-perishable items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**759,771**		0	
Port of Fiscardo		0		0	
Port of Poros	0			**442,455**	
Argostoli					
Sami	0	0			
Lixouri					

Table 96. Scenario 1 continuous variables results for medical items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**4,083**		0	
Port of Fiscardo		0		0	
Port of Poros	0			**2,378**	
Argostoli					
Sami	0	0			
Lixouri					

c. Fixed-Wing Aircraft Transportation

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 1 continuous variables model.

d. Helicopter Transportation

Table 97. Scenario 1 continuous variables results for food and water transported quantities using helicopters, in kg

	Athens airport	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikadi**	**Ceramii**	**Omala**	**Pastra**
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	**40,392**	0	0	0	0
Sami				0	0	0	**64,893**	0		0	0	**24,036**	**5,427**	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 98. Scenario 1 continuous variables results for non-perishable items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	**163,542**	0	0	0	0
Sami				0	0	0	**262,740**	0		0	0	**97,319**	**21,976**	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 99. Scenario 1 continuous variables results for medical items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	**879**	0	0	0	0
Sami				0	0	0	**1,413**	0		0	0	**523**	**118**	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

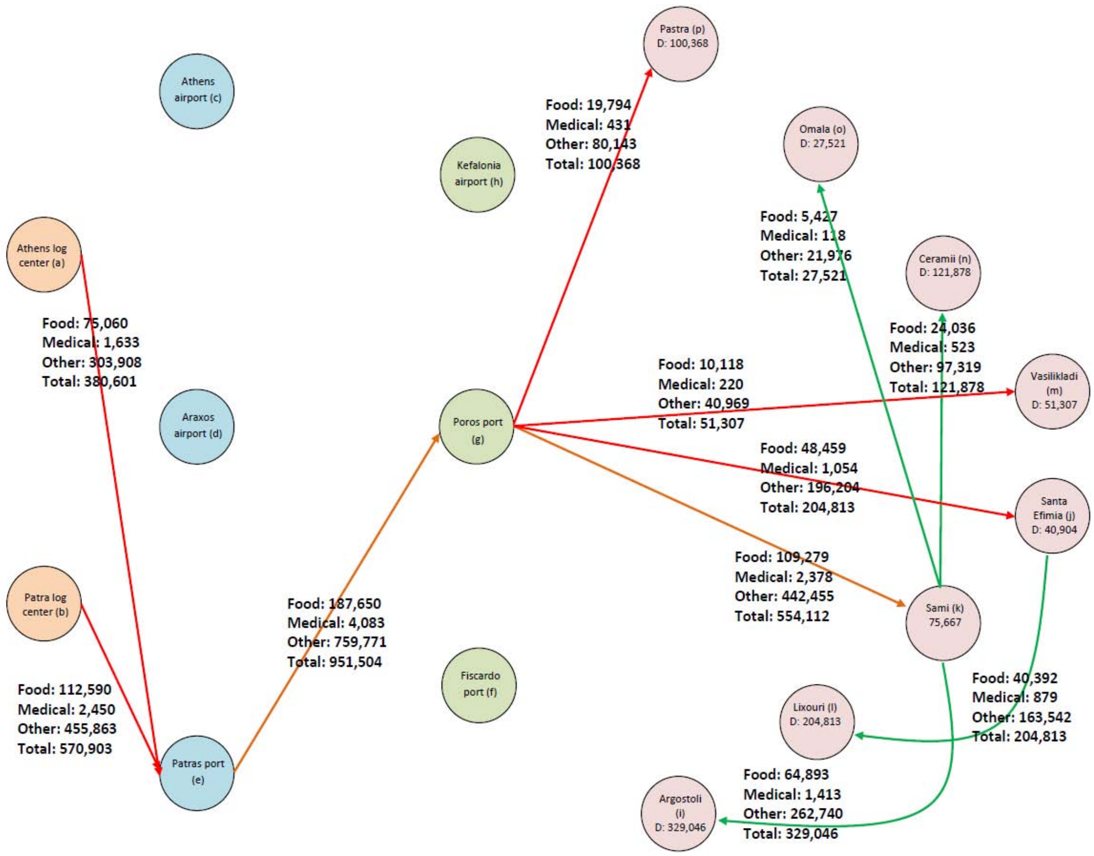

Figure 20. Graphical representation of the optimal solution of the earthquake scenario 1 model with continuous variable (legend the same as the one for Figure 16)

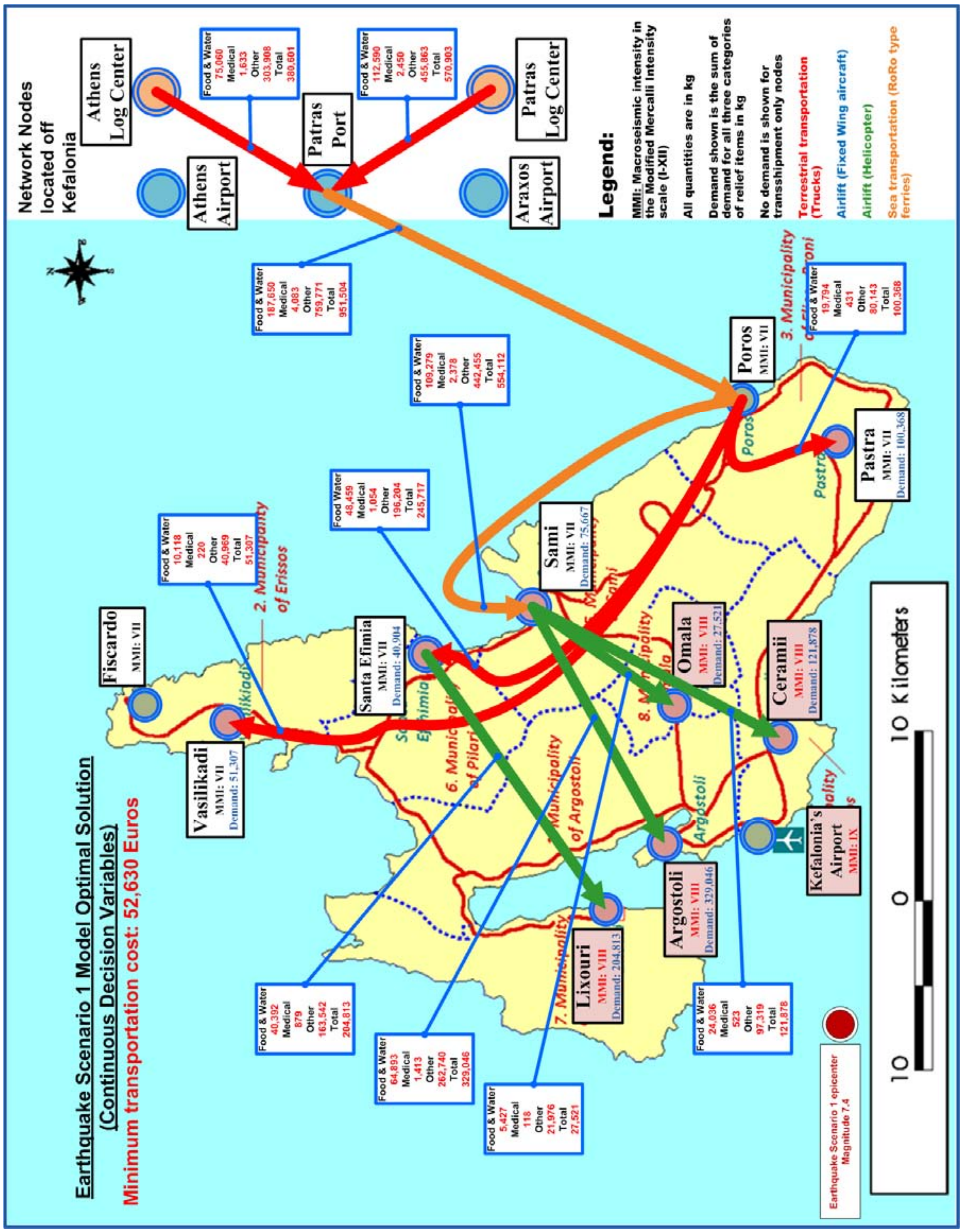

Figure 21. Continuous variables scenario 1 model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

D. SCENARIO 2 CONTINUOUS VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 100. Scenario 3 continuous variables results for food and water transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	75,060											
Patras logistic center		0	112,590											
Port of Fiscardo						0	0			0		0		
Port of Poros														
Airport of Kefalonia				0			0			0		0		
Argostoli				0		0				0		49,257		
Santa Efimia														
Sami														
Lixouri				0		0	0					0		
Vasilikadi														
Ceramii				0		0	0			0				
Omala														
Pastra														

Table 101. Scenario 2 continuous variables results for non-perishable items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	303,908											
Patras logistic center		0	455,863											
Port of Fiscardo						0	0			0		0		
Port of Poros														
Airport of Kefalonia				0			0			0		0		
Argostoli				0		0				0		199,438		
Santa Efimia														
Sami														
Lixouri				0		0	0					0		
Vasilikadi														
Ceramii				0		0	0			0				
Omala														
Pastra														

Table 102. Scenario 2 continuous variables results for medical items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	1,633											
Patras logistic center		0	2,450											
Port of Fiscardo						0	0			0		0		
Port of Poros														
Airport of Kefalonia				0			0			0		0		
Argostoli				0		0				0		1,072		
Santa Efimia														
Sami														
Lixouri				0		0	0					0		
Vasilikadi														
Ceramii				0		0	0			0				
Omala														
Pastra														

b. Ship Transportation

Table 103. Scenario 2 continuous variables results for food and water transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	**18,185**		0		**169,465**
Port of Fiscardo			0		0
Port of Poros					
Argostoli	0				0
Sami					
Lixouri	0		**129,073**		

Table 104. Scenario 2 continuous variables results for non-perishable items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	**73,631**		0		**686,140**
Port of Fiscardo			0		0
Port of Poros					
Argostoli	0				0
Sami					
Lixouri	0		**522,598**		

Table 105. Scenario 2 continuous variables results for medical items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	**395**		0		**3,688**
Port of Fiscardo			0		0
Port of Poros					
Argostoli	0				0
Sami					
Lixouri	0		**2,809**		

c. *Fixed-Wing Aircraft Transportation*

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 2 continuous variables model.

d. *Helicopter Transportation*

Table 106. Scenario 2 continuous variables results for food and water transported quantities using helicopters, in kg

	Athens airport	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikadi**	**Ceramii**	**Omala**	**Pastra**
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	**8,067**	0	0	**10,118**	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	**14,923**	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		**5,427**	**19,794**
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 107. Scenario 2 continuous variables results for non-perishable items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	**32,662**	0	0	**40,969**	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	**60,420**	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		**21,976**	**80,143**
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 108. Scenario 2 continuous variables results for medical items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	**175**	0	0	**220**	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	**324**	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		**118**	**431**
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

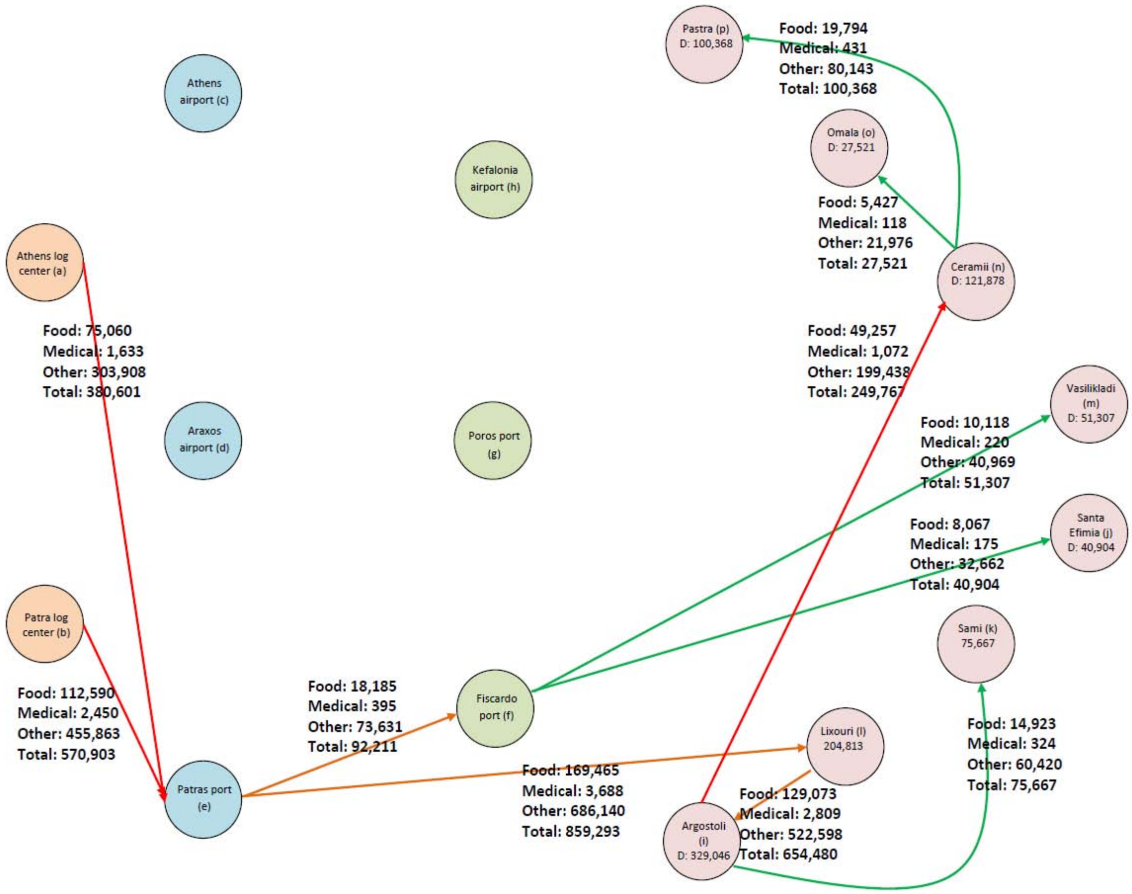

Figure 22. Graphical representation of the optimal solution of the earthquake scenario 2 model with continuous variables (legend the same as the one for Figure 16)

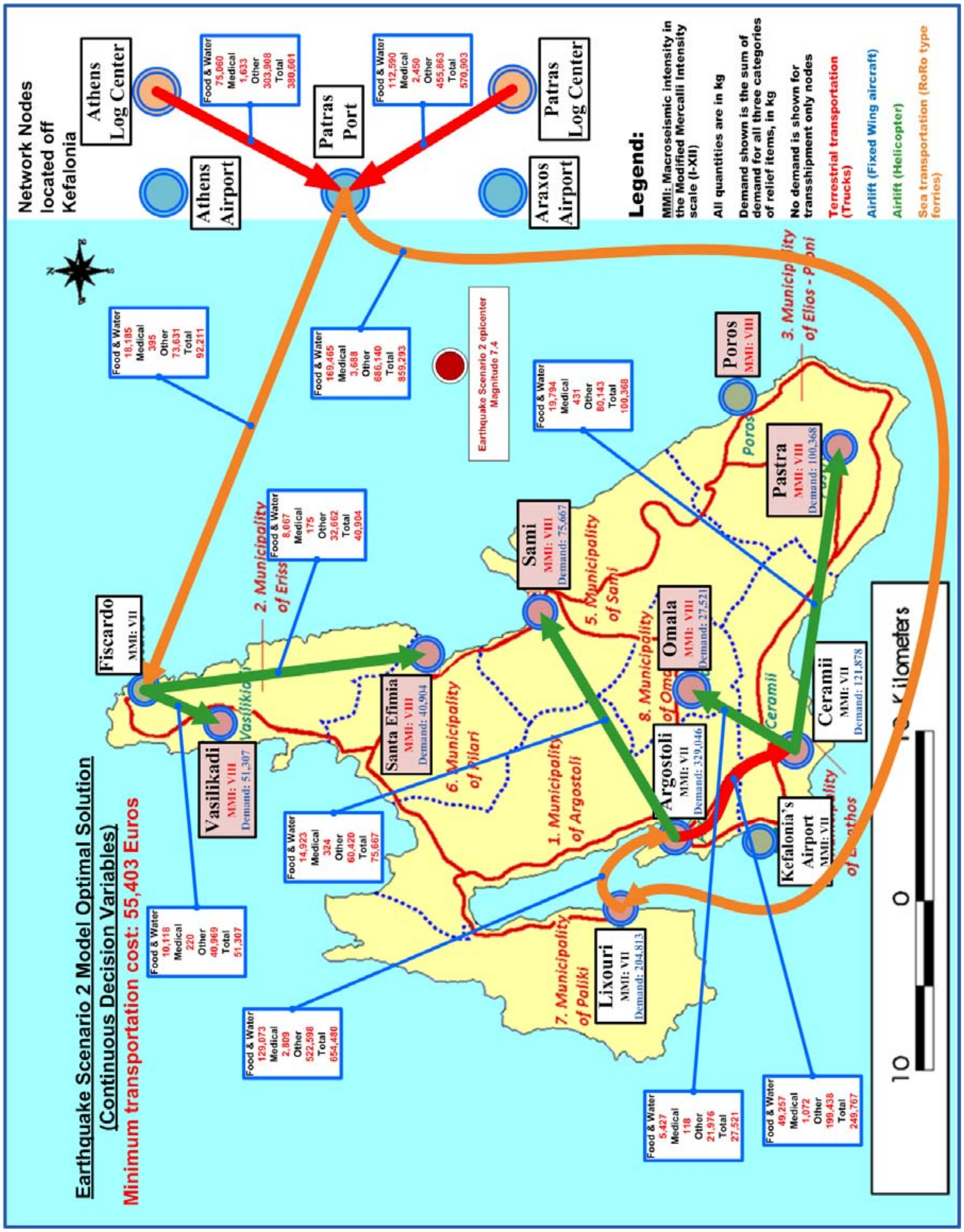

Figure 23. Continuous variables scenario 2 model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

E. SCENARIO 3 CONTINUOUS VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 109. Scenario 3 continuous variables results for non-perishable items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	75,060											
Patras logistic center		0	112,590											
Port of Fiscardo														
Port of Poros						105,285						37,530		19,794
Airport of Kefalonia					0							0		0
Argostoli														
Santa Efimia														
Sami														
Lixouri														
Vasilikadi														
Ceramii														
Omala														
Pastra					0	0						0		

Table 110. Scenario 3 continuous variables results for non-perishable items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	303,908											
Patras logistic center		0	455,863											
Port of Fiscardo														
Port of Poros						426,282						151,957		80,143
Airport of Kefalonia					0							0		0
Argostoli														
Santa Efimia														
Sami														
Lixouri														
Vasilikadi														
Ceramii														
Omala														
Pastra					0	0						0		

Table 111. Scenario 3 continuous variables results for medical items transported quantities using trucks, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	1,633											
Patras logistic center		0	2,450											
Port of Fiscardo														
Port of Poros						2,292						816		431
Airport of Kefalonia					0							0		0
Argostoli														
Santa Efimia														
Sami														
Lixouri														
Vasilikadi														
Ceramii														
Omala														
Pastra					0	0						0		

b. *Ship Transportation*

Table 112. Scenario 3 continuous variables results for food and water transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port		**187,650**			
Port of Fiscardo					
Port of Poros					
Argostoli		0			
Sami		0			
Lixouri		0			

Table 113. Scenario 3 continuous variables results for non-perishable items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port		**759,771**			
Port of Fiscardo					
Port of Poros					
Argostoli		0			
Sami		0			
Lixouri		0			

Table 114. Scenario 2 continuous variables results for medical items transported quantities using ships, in kg

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port		**4,083**			
Port of Fiscardo					
Port of Poros					
Argostoli		0			
Sami		0			
Lixouri		0			

c. *Fixed-Wing Aircraft Transportation*

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 3 continuous variables model.

d. *Helicopter Transportation*

Table 115. Scenario 3 continuous variables results for food and water transported quantities using helicopters, in kg

	Athens airport	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikadi**	**Ceramii**	**Omala**	**Pastra**
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	**0**	**14,923**	0	**10,118**	0	0	0
Airport of Kefalonia				0	0		**64,893**	0	0	**40,392**	0	**0**	**0**	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	**8,067**	0	0	0		**5,427**	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 116. Scenario 3 continuous variables results for non-perishable items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	**0**	**60,420**	0	**40,969**	0	0	0
Airport of Kefalonia				0	0		**262,740**	0	0	**163,542**	0	**0**	**0**	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	**32,662**	0	0	0		**21,976**	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

Table 117. Scenario 3 continuous variables results for medical items transported quantities using helicopters, in kg

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	**0**	**324**	0	**220**	0	0	0
Airport of Kefalonia				0	0		**1,413**	0	0	**879**	0	**0**	**0**	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	**175**	0	0	0		**118**	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

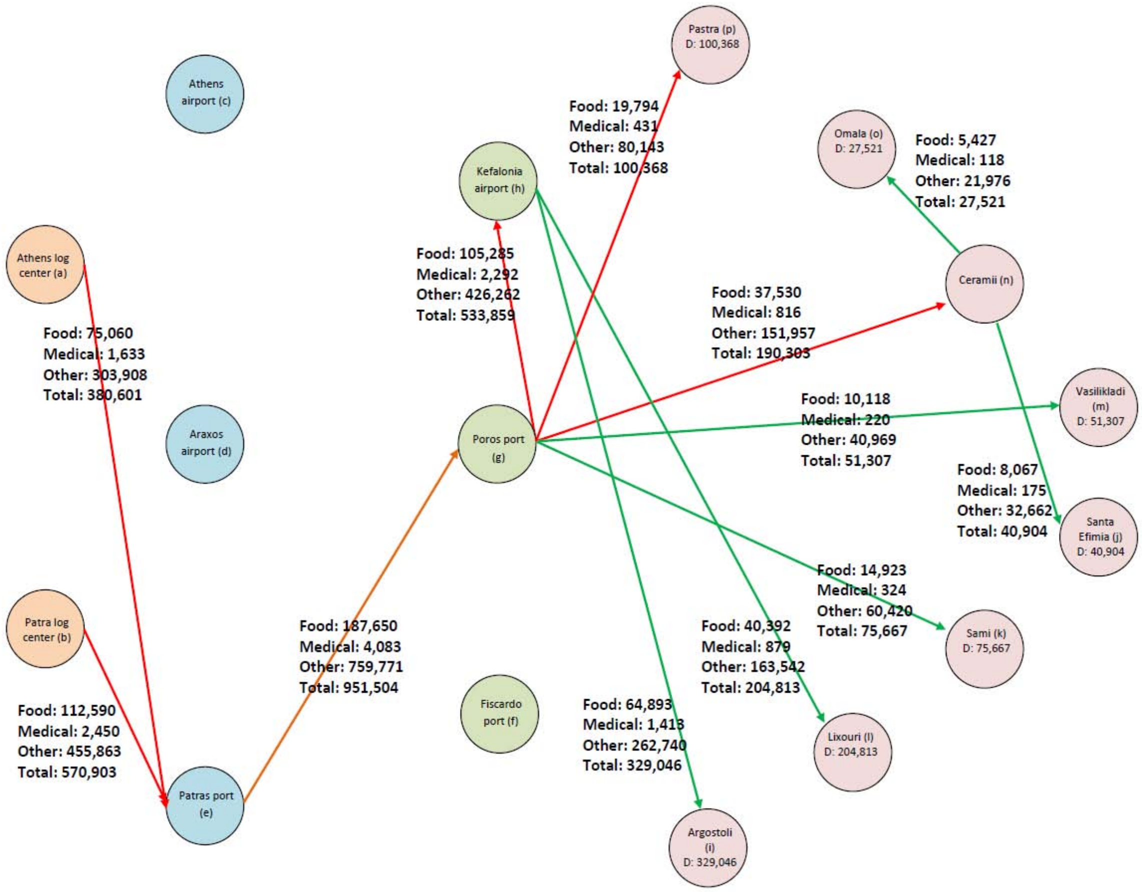

Figure 24. Graphical representation of the optimal solution of the earthquake scenario 3 model with continuous variables (legend the same as the one for Figure 16)

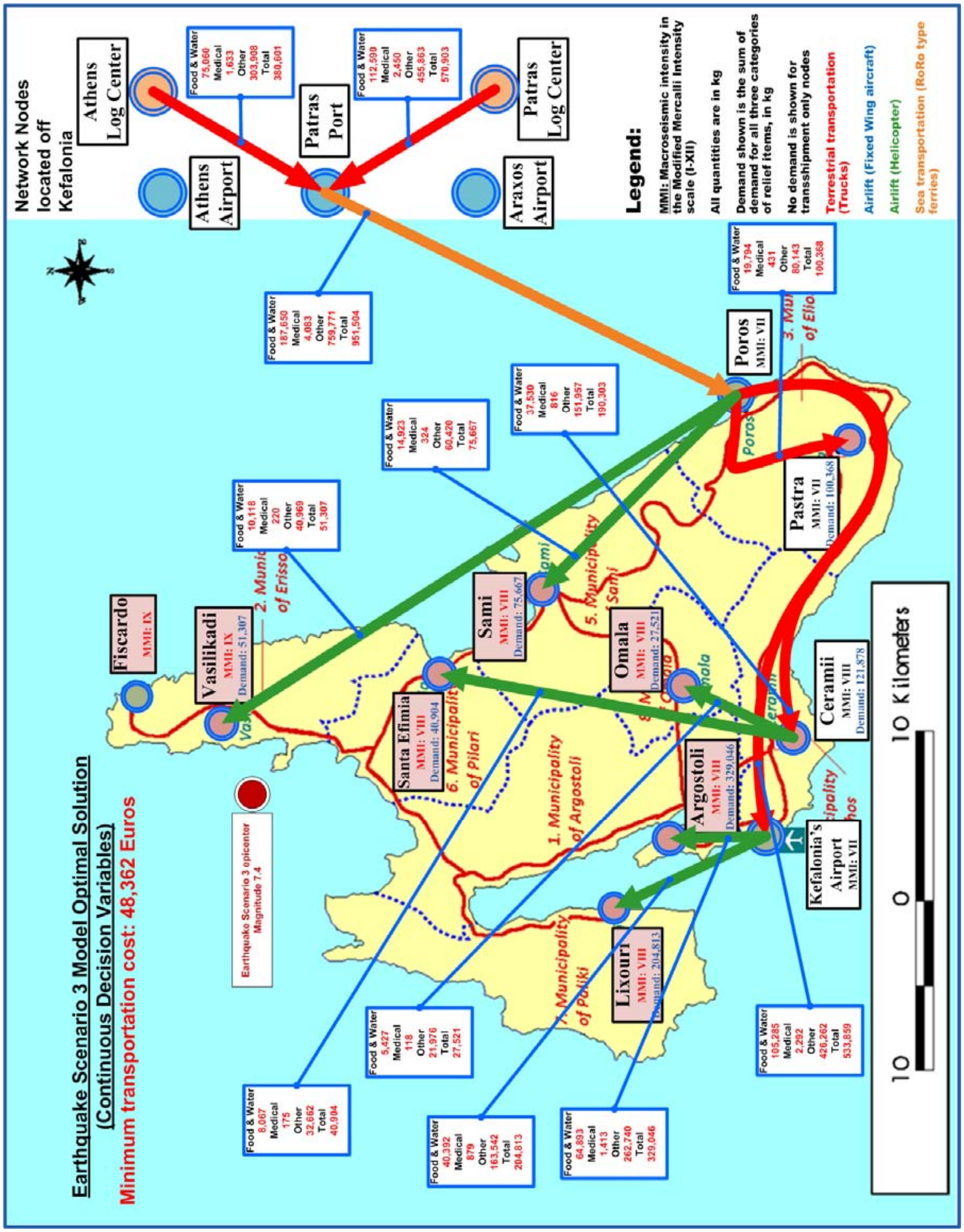

Figure 25. Continuous variables scenario 3 model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

F. BASELINE MODEL INTEGER VARIABLES

1. Numerical Results

a. Truck Transportation

Table 118. Baseline model integer variables results for all types of relief items transported using trucks, in 8-ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**50**											
Patras logistic center		0	**71**											
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	**69**	**7**	0	0	**5**	**14**	**2**	**13**
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

b. Ship Transportation

Table 119. Baseline model integer variables results for all types of relief items transported using ships, in 8-ton loads

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**121**	0	0	0
Port of Fiscardo		0	0	0	0
Port of Poros	0		0	**11**	0
Argostoli	0	0		0	**26**
Sami	0	0	0		0
Lixouri	0	0	0	0	

c. *Fixed-Wing Aircraft Transportation*

No fixed-wing aircraft transportation was required in the optimal solution of the baseline integer variables model.

d. *Helicopter Transportation*

Table 120. Baseline model integer variables results for all types of relief items transported using helicopters, in 12.284 ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	**1**	0	0
Santa Efimia				0	0	0	0		0	0	**1**	0	0	0
Sami				0	0	0	0	0		0	0	0	**1**	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

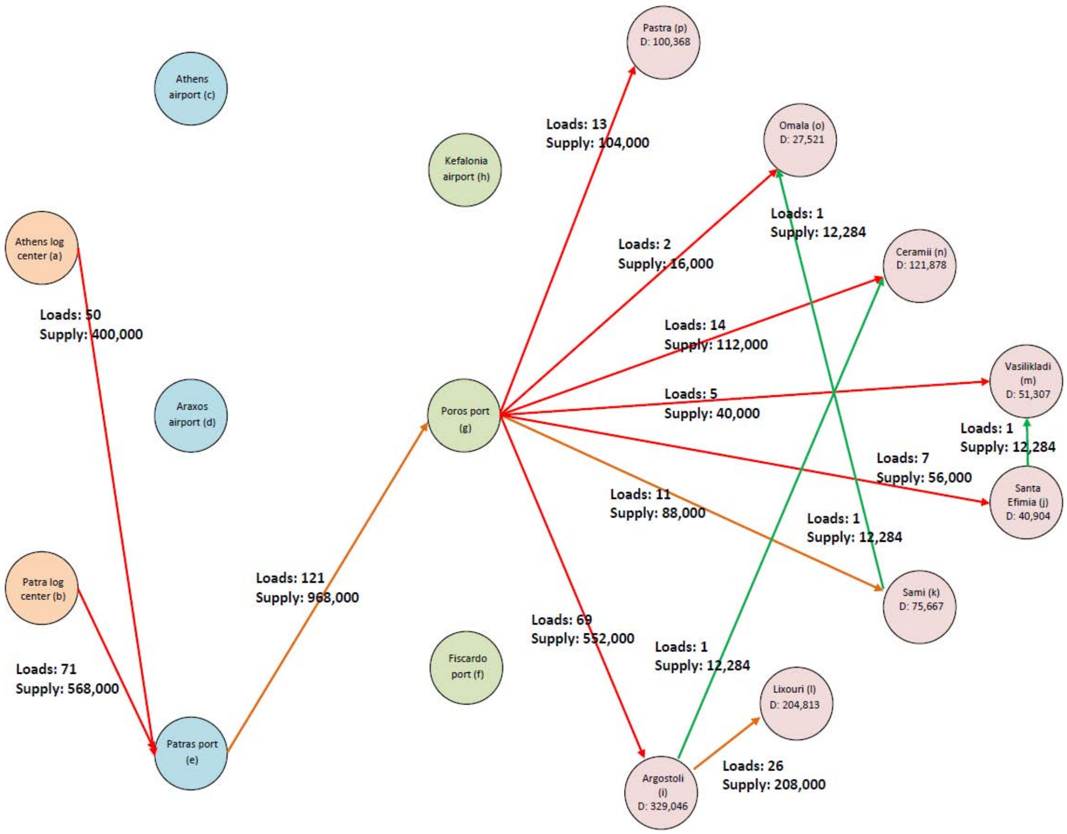

Figure 26. Graphical representation of the optimal solution for the baseline model with integer variables (legend the same as the one for Figure 16)

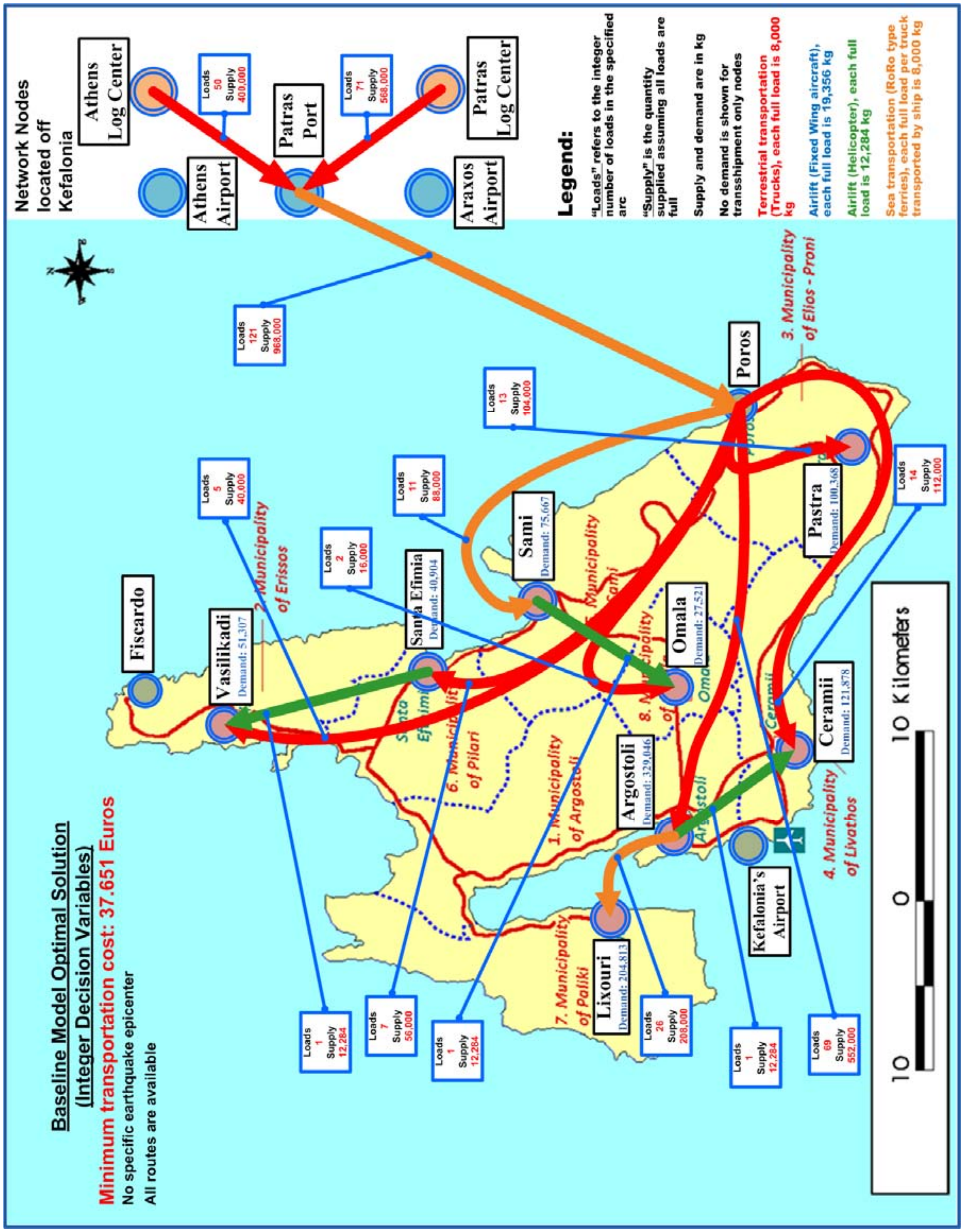

Figure 27. Integer variables baseline model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

G. SCENARIO 1 INTEGER VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 121. Scenario 1 model integer variables results for all types of relief items transported using trucks, in 8-ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**51**											
Patras logistic center		0	**71**											
Port of Fiscardo					0			0	0		0			0
Port of Poros				0				**33**	0		**7**			**28**
Airport of Kefalonia														
Argostoli														
Santa Efimia				0	0						0			0
Sami				0	0			0			0			0
Lixouri														
Vasilikadi				0	0			0	0					0
Ceramii														
Omala														
Pastra				0	0			0	0		0			

b. Ship Transportation

Table 122. Scenario 1 integer variables model results for all types of relief items transported using ships, in 8-ton loads

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	0	**122**		0	
Port of Fiscardo		0		0	
Port of Poros	0			**54**	
Argostoli					
Sami	0	0			
Lixouri					

c. *Fixed-Wing Aircraft Transportation*

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 1 integer variables model.

d. *Helicopter Transportation*

Table 123. Scenario 1 integer variables model results for all types of relief items transported using helicopters, in 12.284 ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	0	0	0	0	0	0
Santa Efimia				0	0	0	**1**		0	**17**	0	0	0	0
Sami				0	0	0	**26**	0		0	0	**0**	**3**	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		0	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	**10**	0	

2. Graphical Illustration of Results

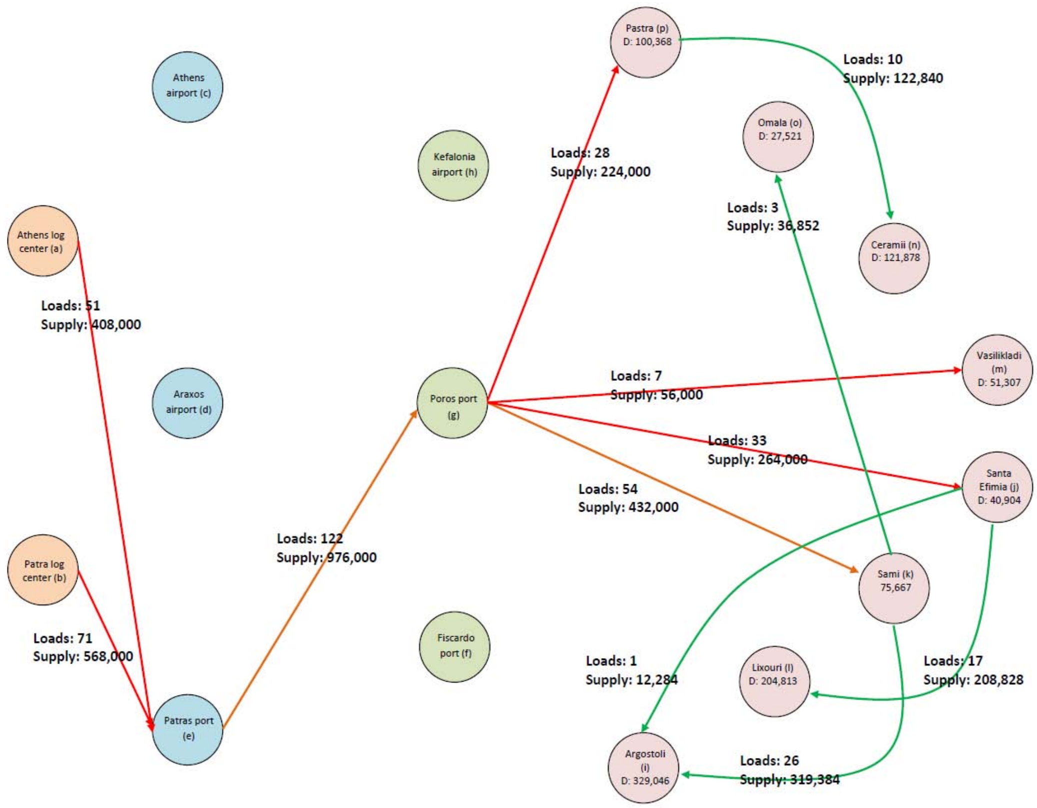

Figure 28. Graphical representation of the optimal solution for the earthquake scenario 1 model with integer variables (legend the same as the one for Figure 16)

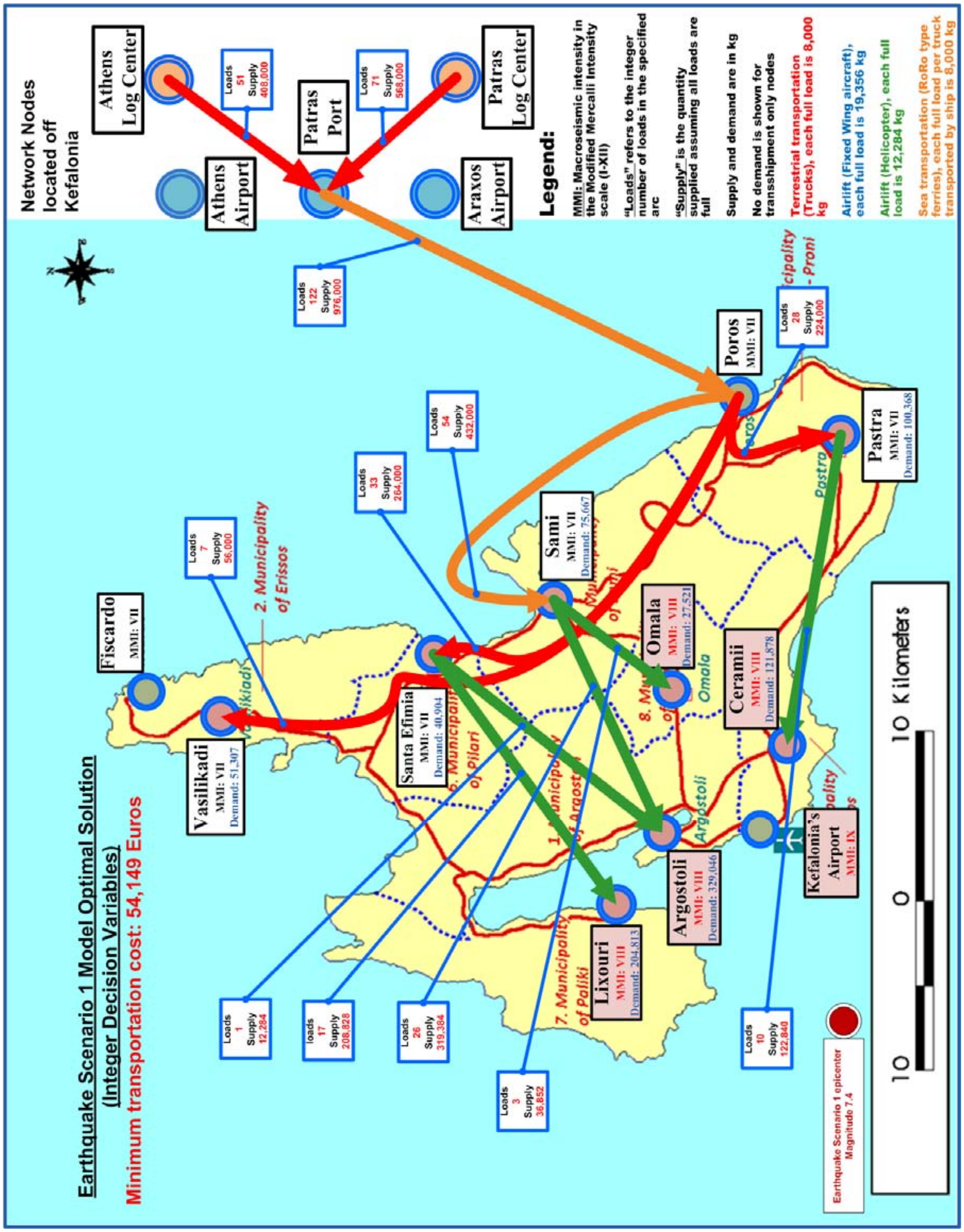

Figure 29. Scenario 1 integer variables model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

H. SCENARIO 2 INTEGER VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 124. Scenario 2 integer variables model results for all types of relief items transported using trucks, in 8-ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**55**											
Patras logistic center		0	**71**											
Port of Fiscardo						0	0			0		0		
Port of Poros														
Airport of Kefalonia				0			0			0		0		
Argostoli				0		0				0		**34**		
Santa Efimia														
Sami														
Lixouri				0		0	0					0		
Vasilikadi														
Ceramii				0		0	0			0				
Omala														
Pastra														

b. Ship Transportation

Table 125. Scenario 2 integer variables model results for all types of relief items transported using ships, in 8-ton loads

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port	**14**		0		**112**
Port of Fiscardo			0		0
Port of Poros					
Argostoli	0				0
Sami					
Lixouri	0		**86**		

c. Fixed-Wing Aircraft Transportation

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 2 integer variables model.

d. Helicopter Transportation

Table 126. Scenario 2 integer variables model results for all types of relief items transported using helicopters, in 12.284 ton loads

	Athens airport	**Araxos airport**	**Patras port**	**Port of Fiscardo**	**Port of Poros**	**Airport of Kefalonia**	**Argostoli**	**Santa Efimia**	**Sami**	**Lixouri**	**Vasilikadi**	**Ceramii**	**Omala**	**Pastra**
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	**4**	0	0	**5**	0	0	0
Port of Poros				0		0	0	0	0	0	0	0	0	0
Airport of Kefalonia				0	0		0	0	0	0	0	0	0	0
Argostoli				0	0	0		0	**7**	0	0	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	0	0	0	0		**3**	**9**
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

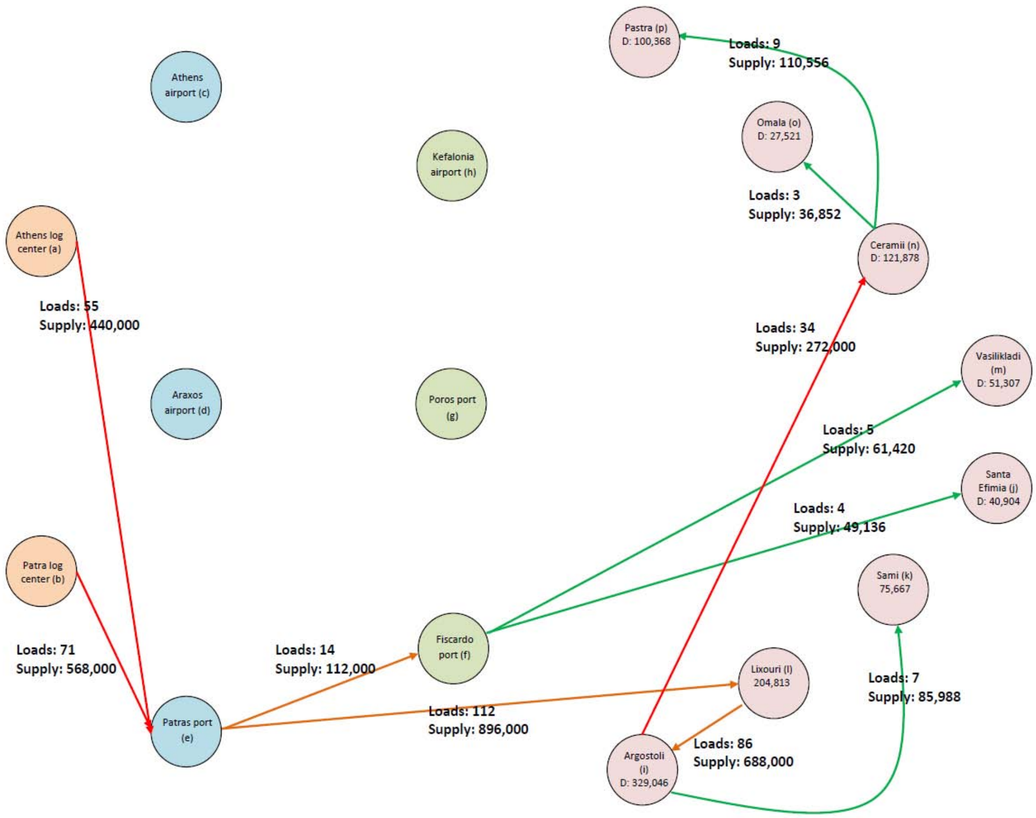

Figure 30. Graphical representation of the optimal solution for the earthquake scenario 2 model with integer variables (legend the same as the one for Figure 16)

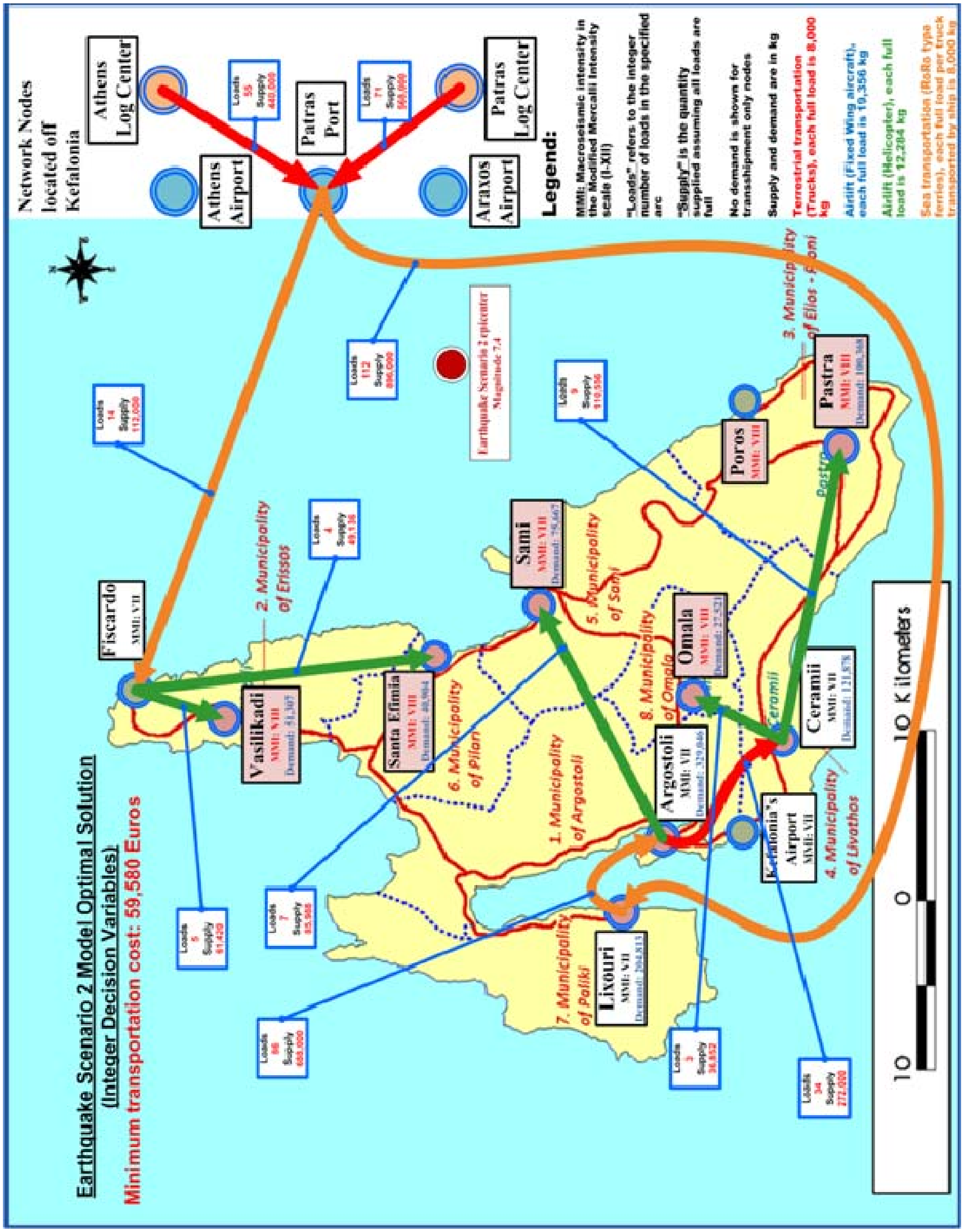

Figure 31. Scenario 2 integer variables model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

I. SCENARIO 3 INTEGER VARIABLES MODEL

1. Numerical Results

a. Truck Transportation

Table 127. Scenario 3 integer variables model results for all types of relief items transported using trucks, in 8-ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens logistic center	0	0	**54**											
Patras logistic center		0	**71**											
Port of Fiscardo														
Port of Poros						**71**						**26**		**8**
Airport of Kefalonia					0							0		0
Argostoli														
Santa Efimia														
Sami														
Lixouri														
Vasilikadi														
Ceramii														
Omala														
Pastra					0	0						0		

b. Ship Transportation

Table 128. Scenario 3 integer variables model results for all types of relief items transported using ships, in 8-ton loads

	Port of Fiscardo	Port of Poros	Argostoli	Sami	Lixouri
Patras port		**125**			
Port of Fiscardo					
Port of Poros					
Argostoli		0			
Sami		0			
Lixouri		0			

c. Fixed-Wing Aircraft Transportation

No fixed-wing aircraft transportation was required in the optimal solution of the scenario 3 integer variables model.

d. Helicopter Transportation

Table 129. Scenario 3 integer variables model results for all types of relief items transported using helicopters, in 12.284 ton loads

	Athens airport	Araxos airport	Patras port	Port of Fiscardo	Port of Poros	Airport of Kefalonia	Argostoli	Santa Efimia	Sami	Lixouri	Vasilikadi	Ceramii	Omala	Pastra
Athens airport		0	0	0	0	0	0	0	0	0	0	0	0	0
Araxos airport	0		0	0	0	0	0	0	0	0	0	0	0	0
Patras port		0												
Port of Fiscardo					0	0	0	0	0	0	0	0	0	0
Port of Poros				0		0	0	**0**	**7**	0	**3**	0	0	**3**
Airport of Kefalonia				0	0		**29**	0	0	**17**	0	**0**	**0**	0
Argostoli				0	0	0		0	0	0	**2**	0	0	0
Santa Efimia				0	0	0	0		0	0	0	0	0	0
Sami				0	0	0	0	0		0	0	0	0	0
Lixouri				0	0	0	0	0	0		0	0	0	0
Vasilikadi				0	0	0	0	0	0	0		0	0	0
Ceramii				0	0	0	0	**4**	0	0	0		**3**	0
Omala				0	0	0	0	0	0	0	0	0		0
Pastra				0	0	0	0	0	0	0	0	0	0	

2. Graphical Illustration of Results

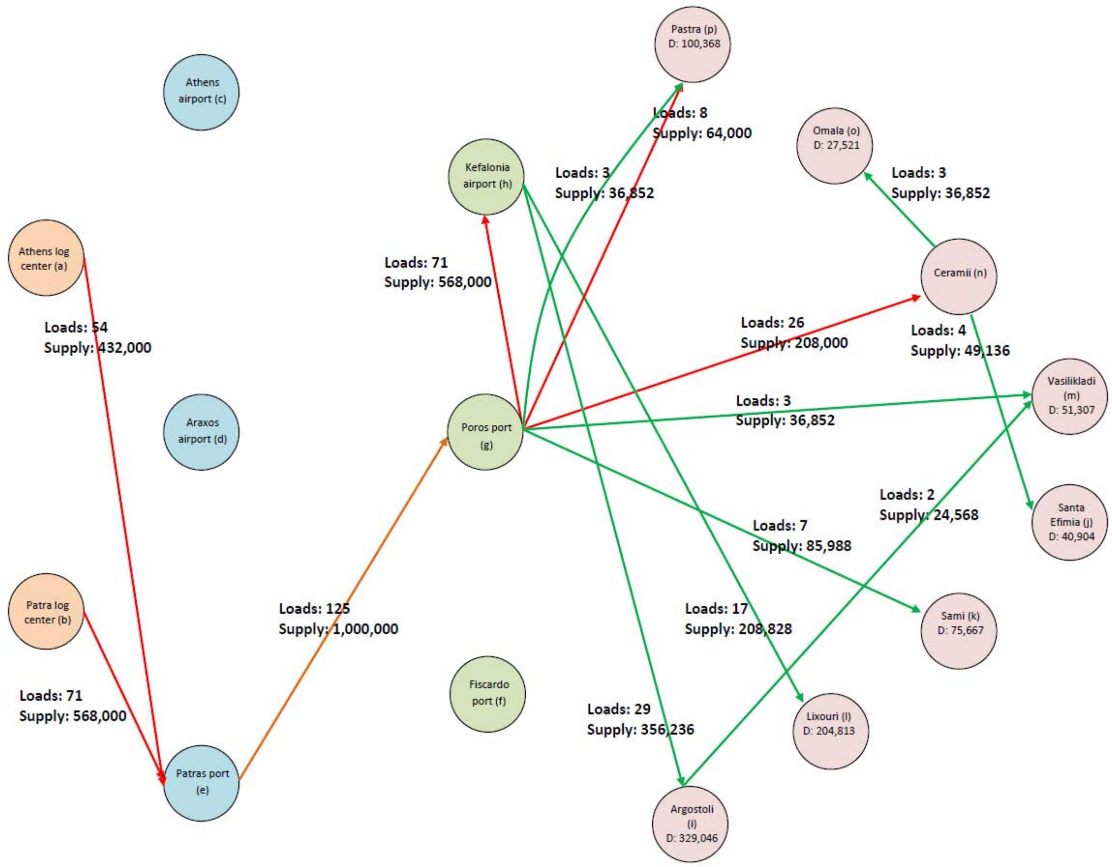

Figure 32. Graphical representation of the optimal solution for the earthquake scenario 3 model with integer variables (legend the same as the one for Figure 16)

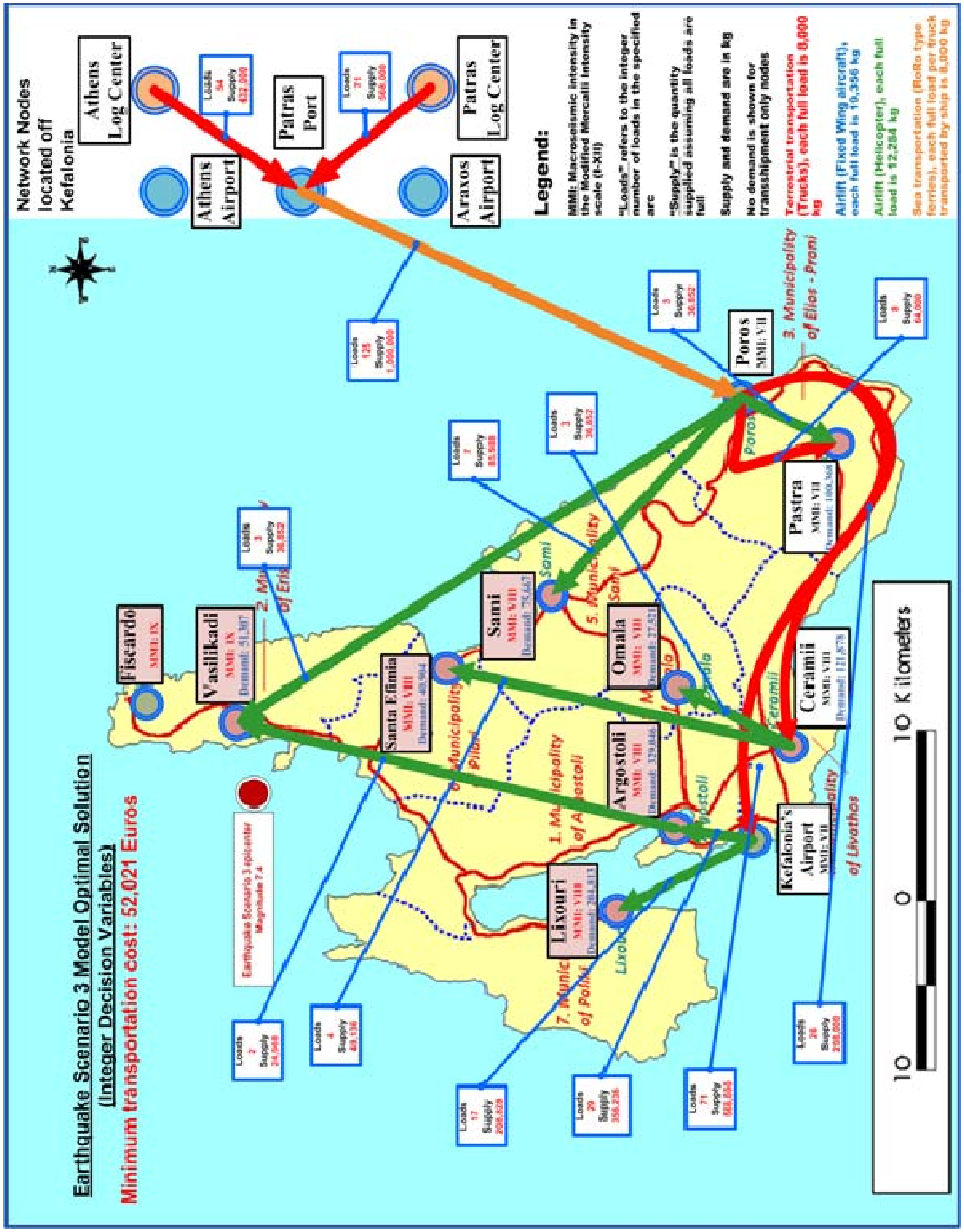

Figure 33. Scenario 3 integer variables model optimal solution (After: Hellenic Republic Ministry of Interior Decentralisation & E-government, n.d.)

J. OBSERVATIONS

As expected, the integer model gave a higher cost of transportation than the continuous, as we can see in Table 130. This was expected because the integer model uses transportation costs allocated per shipments transferred while the continuous model uses transportation costs allocated per kg of relief items transferred. Even though the continuous model seems more efficient and could be used for everyday transportations of goods from the mainland to Kefalonia, we should notice that contingency operations would be scheduled on the basis of shipments that should be transported on the island. Therefore, the integer model seems more realistic.

Table 130. Differences of transportation costs among the eight Scenarios

	Continuous	Integer	Difference	
			Absolute	Percentage
Baseline	36,350 €	37,651 €	1,301 €	3.6%
Scenario 1	52,630 €	54,149 €	1,519 €	2.9%
Scenario 2	55,403 €	59,580 €	4,177 €	7.5%
Scenario 3	48,362 €	52,021 €	3,659 €	7.6%

From the previous chapter we should recall that in accordance with:

- First scenario, five towns were not reachable by land or sea transportation.
- Second scenario, six towns were not reachable by land or sea transportation.
- Third Scenario, seven towns were not reachable by land or sea transportation.

Even though the third scenario projected the most significant damage to the infrastructure of the island, it seems that the second scenario requires more money in order to transfer the required relief items on the island. This happened due to the fact that, in the second scenario, the port of Poros was cut off and then the model was forced to use other ports (Fiscardo, Lixouri and Argostoli). The transportation cost from the port of Patra to the port of Poros is less expensive than the transportation cost from the port of Patra to the ports of Fiscardo, Lixouri, and Argostoli.

Another contributor to the higher transportation costs of the integer model (especially for scenario 3) is the amount of waste in the relief items transferred on the island. The term “waste” describes the surplus material that the integer model decided had to be transported to the island. The continuous model will transport to the island only the exact quantity of relief items demanded. Table 131 shows the mass of waste in the transported relief items. From that table it is implied that scenario 2 causes the largest quantity of waste material to get transferred to the island. We have to state that this waste does not necessarily mean that excess material is actually transported, but that a means of transportation with excess capacity is used for the transportation and the related cost has to be considered, regardless if the truck, ship, helicopter, or aircraft is fully loaded or not.

Table 131. Waste relief items

	Continuous	**Integer**	**Difference**	
			Absolute	**Percentage**
Baseline	951,500	968,000	16,500	1.7%
Scenario 1	951,500	976,000	24,500	2.6%
Scenario 2	951,500	1,008,000	56,500	5.9%
Scenario 3	951,500	1,000,000	48,500	5.1%

The main reason that causes wastage is the assumption that every shipment is equal to the load capacity of the means that performs it. Therefore, it is expected that in several cases the integer model suggests the transportation of excess relief items because it does not have the alternative to choose a smaller shipment of mass than the load capacity of the transportation vehicle. This issue may be resolved if we assume that each vehicle is loaded by using pallets that transfer a standard amount of mass (e.g., 2 tons of items). This would allow for more flexibility in the optimization process, and maybe would result in reduced waste quantities of relief items.

By over-satisfying the demand in the final destinations, the integer model in essence transports relief items all the way from the two initial logistics centers, instead of moving excess items from nearby nodes on the island. This causes the execution of individual delivery of helicopter payloads in conjunction with the delivery of relief items

using trucks, to satisfy demand in a particular node (e.g., in the baseline integer model the optimal solution suggests three individual helicopter shipments from Santa Efimia to Vasilikadi, from Sami to Omala, and from Argostoli to Ceramii, Figure 27). This has to be considered when the model is used for creating a response plan, and the planners have to decide on the necessary adjustments.

X. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

A. CONCLUSIONS

The two models provided a cost estimation interval, which could prove useful for budget purposes. The continuous variables version of the model could be used to estimate the transportation cost under ideal conditions, when all transportations occur with the highest efficiency without any waste in the available capacity. On the other hand, the integer version can provide a more realistic approximation of the actual transportation costs, by taking into account the wasted capacity, when using a fixed cost per load.

Another significant observation is that fixed-wing aircraft airlift capability is not recommended in any of the scenarios. This can be explained as follows:

- Fixed-wing aircraft (in general) are restricted in use because they have to land on specific fields (airports). Therefore in scenario 1, both models would not use airplanes because the Kefalonia airport is cut off.
- Transportation costs of relief items using a fixed-wing aircraft are of the most expensive among the four transportation means.
- There were enough helicopters, ships, and trucks and their capacity constraints were not binding. This means that, in the given timeframe of three days, and with the available quantities of each means of transportation, all of the necessary quantities of relief items can be transported on the island without using fixed-wing aircraft.

After considering all the observations, we infer that the methodology developed during the course of this project can be used as the basis for a framework to develop disaster relief transportation plans. The optimal solutions cannot be considered directly applicable to a real world situation. However, the model can be solved very fast (from a few seconds to 3 hours for the scenarios we used), and the results can be used with minor modifications to produce an applicable transportation plan in a short time. This also means that the models can be resolved as many times as required, when and if more accurate information about the actual impact of the earthquake becomes available.

One more conclusion is that the graphical illustration of the results on an actual map of the affected area can become a very useful tool for interpreting the results, and can assist the planners to decide on the necessary adjustments before implementing the transportation plan. In the following paragraphs, we describe some of the proposed applications for the developed methodology.

B. PROPOSED APPLICATIONS

1. Positioning of Means of Transportation

In the particular setting for which we developed the methodology, the optimal solutions in all the tested scenarios suggest that the helicopters used in the relief operations have to be located on the island. This information is useful in the initial stages of the planning, when the decision makers in charge of coordinating the operations have to decide on the deployment of the means of transportation.

2. Prepositioning of Materials and Assets

In preparing for an earthquake there is no point in storing perishable relief material, since there is no way to accurately predict when the next earthquake will occur. However, after looking at the results from the two models, we can infer that non-perishable material can be prepositioned near Patras and in Athens. In general, the methodology can indicate the possible locations for the prepositioning of non-perishable relief items, since they will have to be readily available when an earthquake occurs. The impact on the transportation cost, of prepositioning material in alternative locations, can then be estimated using the two models. In the three scenarios we tested we assumed that all the necessary relief items were readily available in two locations, when the operations began.

3. Basis for Scheduling the Shipments

The optimal solutions provide the quantities transported in each route, the number of shipments, and the means of transportation. This information can provide the basis for developing the detailed scheduling of all the necessary shipments of materials, using a given number of available vehicles.

4. Prioritizing Shipments of Different Types of Relief Items

Different types of relief items do not necessarily have equal priority when satisfying demand. In some cases water and food might be more vital than items related to sheltering the affected population. Adjusting the restrictions in the continuous variables model can provide timely, prioritized transportation plans according the type of the relief items shipped.

5. Determining the Required Capacity for Implementing the Transportation Plan

In the scenarios we tested the means of transportation dedicated to the relief effort were adequate to fulfill the requirement within the given timeframe. The models can be adapted to include additional nearby islands in the Ionian Sea, such as Ithaka, affected by the same catastrophic event. In this case the models will provide with a quick answer as to what is the required number of trucks, helicopters, ships, and aircraft, to undertake the transportation of the required relief items.

6. Evacuating Population From the Affected Area

Modifying the two models by reversing the direction of the flow and considering population to be evacuated, instead of relief items, will allow the same methodology to be used to provide an evacuation plan.

7. Transporting Aid Workers in the Affected Area

Modifying the two models to consider aid workers and equipment, instead of relief items, will allow the same methodology to be used to provide a plan for the initial transportation of aid workers to the affected area.

C. SUGGESTIONS FOR FURTHER RESEARCH

This project is a beginning, intended to prove the usefulness and the feasibility of using linear programming methods to develop a framework for disaster relief planning. After completing the project, we realize that much more work is required to refine the methodology. We mentioned many of these refinements or alternative applications in the previous paragraph.

A different direction for further research would be to test the transportation plans developed with the two models using simulation techniques. This will account for the effects of variability in the underlying assumptions that the models were based on.

D. SUMMARY

Several current earthquakes have revealed the complexity and the magnitude of global emergency relief operations as well as the critical need for effective and efficient disaster relief logistics. The irregular demand patterns and unusual constraints inherent in large-scale emergencies present unique challenges to logistic systems. Indeed, the logistical needs frequently surpass the capabilities of current emergency response approaches.

A great deal of research has been done on linear programming models for optimizing disaster response logistics. So far there has been no application of these methods in a Greek environment for post-earthquake operations. Since the Hellenic Armed Forces bear a significant portion of the responsibility for conducting these operations, the development of a model applicable to the Greek environment could prove to be a very useful public safety tool.

The focus of this project was the formulation and the solution of an optimization model for logistics support distribution of aid, during post-earthquake disaster relief operations, on an island in the Ionian Sea. Therefore, a mathematical model describing the movement of different commodities, using multiple transportation modes, from a number of origins to a number of destinations, over transportation network, within a given time frame was developed. The model minimized transportation costs within a given response time, within the required restrictions for post-earthquake disaster relief on Kefalonia, one of the seven major Greek Ionian islands that has a long earthquake history. The model was tested on several hypothetical earthquakes and it provided reasonable solutions. Based on these solutions, we made recommendations for further development.

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